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Design, development and techno economic analysis of novel parabolic trough collector for low-temperature water heating applications

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ABSTRACT

The primary objective of this experimentation is to develop and evaluate indigenous PTC capable of producing hot water for low-temperature applications. A new parabolic trough collector is designed; which is easy to accumulate and transport. It allows the easy replacement of receiver pipe, reflector sheet, and heat transfer fluid. The modern design also allows changing the trough's geometrical dimensions. The design has provision for attaching an automatic tracking system and glass cover. This Novel PTC is tested with three different attachments, viz. Manual tracking without glass cover, Manual tracking with glass clover and Automatic tracking without glass cover. Experimental, Optical and Theoretical efficiencies calculated for all three PTC systems. Average experimental efficiency of PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 11.83%, 13.50%, and 14.94 % respectively. Brief, economic analysis carried out for all three PTC systems. Cost of water heating per kg for manual tracking PTC system is only 0.3/- INR, and for Manual tracking with a Glass cover and Automatic tracking, it is equivalent to 0.4/- INR. The payback period for all is equivalent to 4 years for a PTC system for manual tracking and for PTC systems of Manual tracking with a Glass cover and Automatic tracking it is found equivalent to 5 years. Experimentation conducted in March 2020 at the specific location in Godhra, Gujarat, India.

1. Introduction

The application of solar-powered systems is the finest solutions to reduce the effects of global warming. Solar thermal Equipment is capable of replacing almost all conventional types of Equipment. Solar thermal types of Equipment mainly classified into two categories concentrated and non-concentrated collectors. Solar parabolic trough collector is categorized into two parts. First is a full-grown technology mostly used in electricity generation [1–5]. It has a higher heating range, so a wide variety of applications are possible [6].

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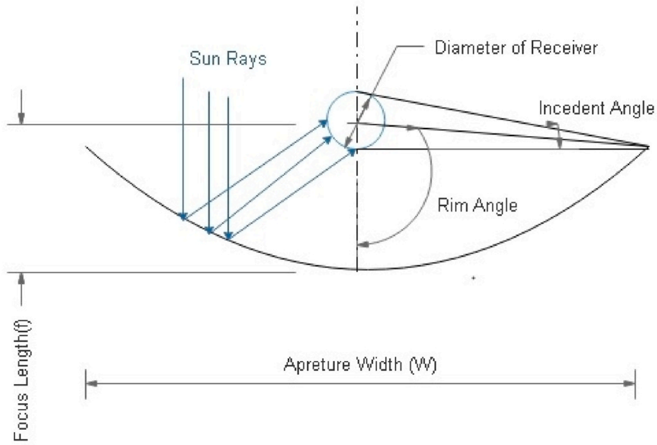

Fig. 1. Geometry of trough [7].

The applications include water purification, industrial process heat, refrigeration, air conditioning and heating, food processing etc. [7–10]. This second category has a low to medium temperature range. Most of the researchers are working on this second category of parabolic trough collectors [11]. PTC is a line focusing on concentrating solar collector. Reflector, receiver or absorber, structure, tracking system, and storage system are physical parts of PTC. Reflectivity, intercept factor, mass flow rate, HTF and applications are the main core areas of PTC in which researchers work [12,13].

The physical structure of PTC is characterized by its geometrical parameters; rim angle, width, length, height, and focal length [14]. Schweitzer et al. industrialized the Ultimate Trough with a length of 247 m, and an aperture of 7.5 m makes it the largest collector. They predicted to reduce ground cost by 20–25%. The structure of the PTC has a different width and length. It has a length of 1 m–247 m [15]. investigated all geometrical parameters of PTC and the cost of heat production. They carried out economical, exergy and energy analysis. It found that the exergy efficiency = 29.22%, energy efficiency = 35.55% and heat cost = 0.0142 $/kWh as an optimal result.

Heat transfer fluid (HTF) transfers heat energy gained by absorber from solar beam radiations. Generally, water is used as HTF for low to medium temperature applications. In contrast, synthetic oil, molten salt, etc., are used for medium to high-temperature applications. Mono and hybrid nanofluids are in the experimental stage; many research types are working on it [16,17]. The utilization of nanofluid for solar thermal power storage is accompanied by specific difficulties like production cost, instability, agglomeration and erosion [18]. Marefati et al. [19] analyze the numerical modelling of PTC using MATLAB for four major cities of Iran. They were considered mass flow rates, concentration ratio and incident angle modifier as some useful parameters. The effect of nanofluid on performance also evaluated.

A reflector is the most important part of PTC. The performance of PTC is highly dependent on reflector quality. The reflector represents the optical efficiency of PTC. Aluminium foil, aluminium sheet, SS sheet, Acrylic mirror, etc., are used as a reflector [20]. Pandey et al. [21] numerically studied the effect of arc-plug inserts into absorber tube for thermal enhancement of the PTC. For inserts with factor R = 0.879 and R = 1; PTC shows the maximum thermal efficiency.

The economic analysis required for check-in economic viability of the system. It is necessary after technical analysis of any design and before launch in the market. Kalogirou [22] studied economics, environmental protection and thermal performance of thermosiphon SWHS. Detailed economic analysis carried out and found a payback period of 2.7 years with electricity backup, 4.5 years with diesel backup. Panchal et al. [2] investigated the annual performance of SBSWVT at Mehsana, Gujarat. Detailed economic analysis was carried out with annual cost calculations and a payback period. After one year of research, the price of water produced found around 0.71 Rs per litre and payback 176 days [23,24].

This work is an extension work of Upadhyay et al.[25]. Three different reflectors and six other receiver pipes were investigated. Chrome reflector with graphite coated copper receiver pipe was concluded as the best working pair. Further experimentation carried out using this best-suited pair with various attachments. This paper deals with design, development and evaluating low-cost PTC generating hot water for low-temperature applications. Three different attachments Manual tracking, with and without glass cover and Automatic tracking attached to newly developed PTC are tested. Experimental, Optical and Theoretical efficiencies calculated for all three PTC systems. Detailed economic analysis carried out for all three PTC systems. Besides, CO_2 Reduction and carbon credit earned is calculated.

2. Design and development of PTC

A PTC design's critical components are trough length, focal length, aperture width, and rim angle [26–28]. Designing a trough collector is a challenging task. Not only crucial parameters but other affecting parameters like average wind speed, HTF, application, no. of loops, storage device etc., are also considered while designing as they also affect the efficiency of a system.

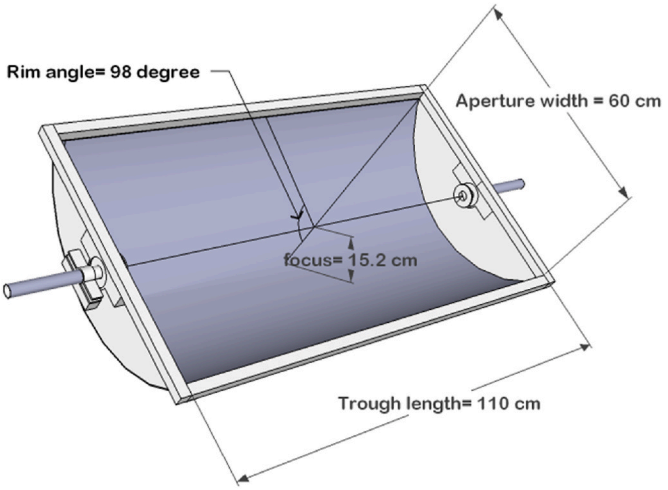

Fig. 2. Geometrical descriptions of the trough [14].

Fig. 3. Parts of PTC

After bearing in mind all the beyond constraints, an innovative PTC is designed. This PTC is easy to accumulate and transport. Specific capability to accommodate different absorber pipes, various reflector sheets and HTF is added in this PTC. Present design also allows scaling of trough size by changing its geometrical dimensions. The design has a facility for attaching an automatic tracking device and storage system. Leakage issues are commonly observed inflexible joints in most of the PTC known till today. This design solves the problem of leakage by eliminating flexible joints applied to the receiver.

The critical parameters of the PTC are shown in Fig. 1.

An appropriate analytic representation of a parabola is [26],

$$Y = 1/4f\ X^2 \tag{1}$$

The distance between the parabola vertex and the focal point is called focal length (f). Where X and Y are the axes, it is used to find the shape of a parabola.

Table 1
Final Dimensional values.

Description	Values
Collector length	1.1 m
Collector Width	0.60 m
Concentration ratio	**11.66**
Focal distance	0.156 m
Receiver inner diameter	0.018 m
Receiver outer diameter	0.02 m
Receiver Length	0.90 m
Rim angle	98^0
Storage tank capacity	30 L
Receiver material	Copper coated black
Reflector	Chrome sticker

Table 2
Initial capital cost.

Sr.	Details of Component	Quantity	Price/Quantity (INR)	Total Price (INR)
1	Model Material	–	1400	1400
2	Fabrication cost	–	1200	1200
3	Thinner	200 ml	30	30
4	Blue colour	250 ml	50	50
5	Black graphite paint	250 ml	50	50
6	3/4 pipe cpvc	3 feet	33.33	100
7	3/4 union cpvc	4	60	240
8	3/4 valve cpvc	1	200	200
9	cpvc sealant	100 gm	120	120
10	Teflon tape	5	20	100
11	Bearing F 205	2	160	320
12	Tank	30 L	300	300
13	Quick Sealant	5	10	50
14	3/4 FT cpvc	4	20	80
15	Pipe	10 m	25	250
16	GI Sheet	8 Square feet	15	120
17	Insulation material	4 m	52.5	210
18	Chrome Reflector Sticker	8 Square feet	20	160
19	Copper receiver pipe	3 feet	50	150
20	Miscellaneous	–	–	200
A	**Total (Sr.No.1-20)**	**Manual Tracking**		**5330**
21	Motor 10 RPM	1	200	200
22	LDR Sensors	2	20	40
23	Wires	10 m	10	100
24	Microcontroller Device (Arduino)	1	350	350
25	Pulley plastic	1	100	100
26	Solar Panel (3W,12V,10′x14′)	1	400	400
27	Rope	1	60	60
			Sub Total	1250
B	**Total (Sr.No.1-27)**	**Automatic Tracking**		**6580**
28	Glass Cover	8 Square feet	220	1760
C	**Total (Sr.No.1-20 & 28)**	**Manual tracking with a Glass cover**		**7090**

Rim angle, focal length and aperture width are the main three parameters to define the cross-section of parabolic trough completeness, i.e. shape and size. Any two known parameters are necessary to calculate the third one. The ratio of the aperture width to the focal length can be articulated as a function of the rim angle [28].

$$\frac{a}{f} = -\frac{4}{\tan\psi} + \sqrt{\frac{16}{\tan\psi^2} + 16} \tag{2}$$

The aperture area is calculated by the product of the length of the trough (l) and aperture width (a) [28].

$$A_a = a \, x \, l \tag{3}$$

The surface area of a parabolic trough may be essential to determine the material required for the trough. The area is premeditated as follows [28]:

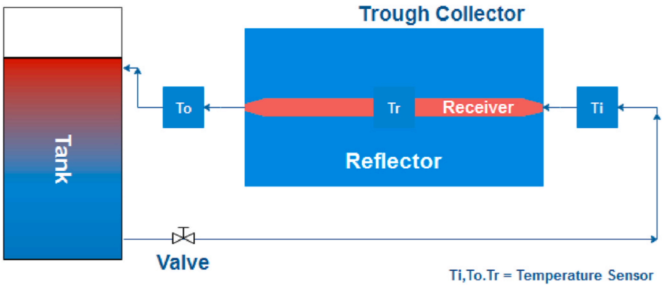

Fig. 4. Schematic diagram of the Experimental process.

Fig. 5. Photograph of actual setup.

$$A_s = \left(\frac{a}{2}\sqrt{1+\frac{a^2}{16f^2}} + 2f.ln\left(\frac{a}{4f} + \sqrt{1+\frac{a^2}{16f^2}}\right)\right).l \tag{4}$$

The concentration ratio (C) is the vital factors of the collector. It is significant for the possible operating temperatures of the PTC system. The General concentration ratio is found by the aperture area (A_a) ratio to the receiver area (A_r) (1), (3) and (4),

$$C = \frac{A_a}{A_r} \tag{5}$$

In the existing design, trough length is 110 cm, aperture width (a) = 60 cm and it is fixed to the bearing shown in Fig. 2. The Main Components of PTC are shown in Fig. 3. Table 1 shows the various dimensions of PTC [14] (see Table 2).

3. Experimental process

The key objective of this experimentation is to evaluate the newly developed parabolic trough collector. This PTC is capable of heating water for domestic needs. Novel PTC with three different attachments like Manual tracking, with and without glass cover and Automatic tracking, were experimenting in March at the specific location of Godhra, Gujarat, India. All Three PTC has bared copper coated with black graphite paint receivers and chrome sticker as a reflector.

Calibrated PT 100 type thermocouples measure the temperature at different locations. Solar radiation is measured by a digital solar power meter. A digital anemometer measures wind speed. All temperature sensors are connected to a temperature scanner for

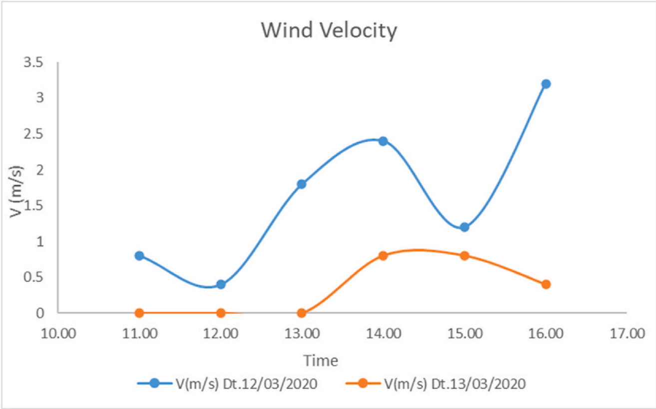

Fig. 6. Wind velocity vs Time.

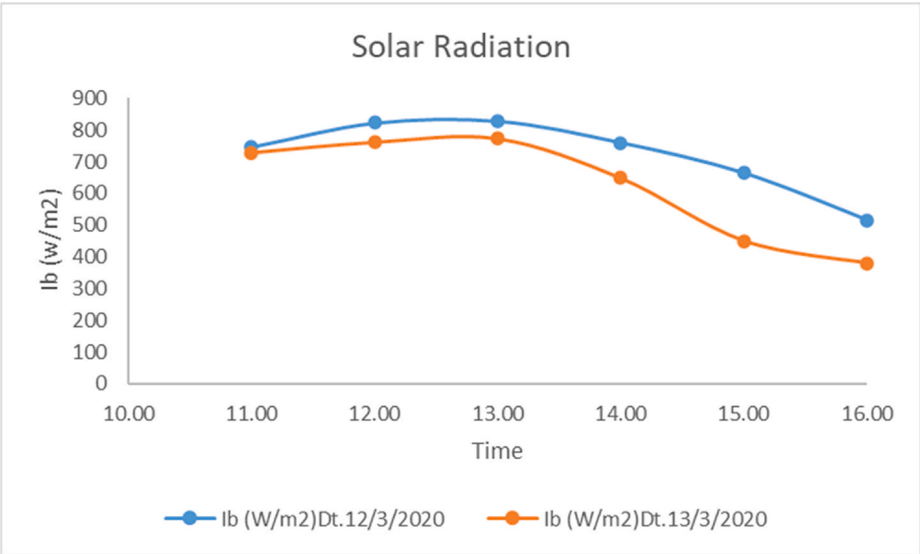

Fig. 7. DNI vs Time.

monitoring and recording the data. Anemometer and solar power meter are being associated with a computer to monitor and record the data.

The experimental process's schematic diagram is shown in Fig. 4, and a photograph of the actual setup shown in Fig. 5 (see Fig. 6).

3.1. Calculations

3.1.1. Experimental thermal efficiency

Thermal efficiency can be found in two ways experimental and theoretical. This work is concentrated on experiment analysis, so the experimental thermal efficiency is found out using the following equation [26,29] (see Figs. 7 and 8).

$$\eta_{exp} = \frac{Q_{u\ exp}}{I_b \cdot A_a} \tag{6}$$

Where,

$$Q_{u\ exp} = M \cdot C_p \cdot (T_o - T_i) \tag{7}$$

3.1.2. Optical theoretical efficiency

Optical efficiency plays a significant role in the calculation of the overall theoretical efficiency of the PTC system. Optical efficiency plays an analytical role to check the perfectness of the system. The formula for finding theoretical optical efficiency is as follows [21,

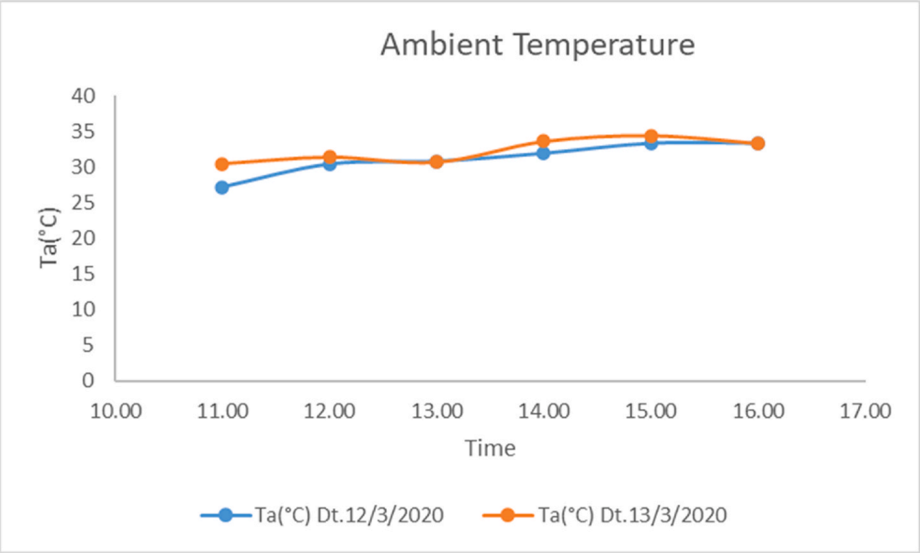

Fig. 8. Atmospheric Temperature vs Time.

22,30].

$$\eta_{opt} = \alpha \cdot \rho_m \cdot \gamma \cdot K \tag{8}$$

Where α and ρ_m are material properties and K is equal to 1 when tracking is provided. The following equation can find the intercept factor. I*(w)* is the reflected radiations. *A* and *B* indicate a range equal to a receiver's outer diameter [26].

$$\gamma = \frac{\int_A^B I(w)dw}{\int_{-\infty}^{+\infty} I(w)dw} \tag{9}$$

3.1.3. *Theoretical thermal heat loss*

Theoretical thermal heat loss summarises convective heat transfer coefficient (h_w) and radiative heat transfer coefficient ($h_{r,r\text{-}a}$). Convection heat transfer may get reduced due to wind between a receiver and ambient air. It can find out by the following equation [26,29–31].

$$h_w = \frac{N_{ua} \cdot k_a}{D_{r.ext}} \tag{10}$$

Where N_{ua} represents Nuselt number of air and can be determined by the following equation,

$$N_{ua} = 0.4 + 0.54{*}Re_a^{0.53} \quad \text{For} \cdot 0.1 \cdot < \text{Re}_a \cdot < 1000 \tag{11}$$

$$N_{ua} = 0.3{*}Re_a^{0.6} \quad \text{For} \cdot 1000 < \text{Re}_a < 50,000 \tag{12}$$

Where the following equation can calculate the Reynolds number of air (Re_a)

$$Re_a = \frac{V \cdot D_{r.ext}}{\upsilon_a} \tag{13}$$

And radiative heat transfer coefficient ($h_{r,r\text{-}a}$) found by,

$$h_{r,r-a} = \varepsilon \cdot \sigma \cdot (T_r + T_a) \cdot \left(T_r^2 + T_a^2\right) \tag{14}$$

The sum of equation (10) and equation (14) can be found in the overall heat loss coefficient.

$$U_L = h_w + h_{r,r-a} \tag{15}$$

3.1.4. *Theoretical efficiency*

Theoretical efficiency found by the following equation [26,31].

Table 3
Annual cost of water heating (ACWH).

Data	Manual Tracking	Automatic Tracking	Manual tracking with a Glass cover
ΔT	19.0	19.4	21.4
ACWH	1338.1	1364.2	1504.8

$$\eta_{theo} = \eta_{opt} - \frac{U_L \cdot A_r \cdot (T_r - T_a)}{I_b \cdot A_a} \tag{16}$$

3.1.5. Beam radiation

Concentrating solar collectors use direct solar radiation for transforming solar energy into useful heat energy. Solar radiations are measured by a digital solar power meter, which measures total solar radiation. For predicting beam radiation from a total radiation Hottel model (1976) is used [26,32,33].

$$a_0 = 0.2538 - 0.0063\ (6 - A')^2$$

$$a_1 = 0.7678 + 0.0010\ (6.5 - A')^2$$

$$k_1 = 0.249 + 0.081\ (2.5 - A')^2$$

$$I_b = I_o \left(a_0 + a_1 \times e^{-\frac{k_1}{\cos\theta_z}} \right) \tag{17}$$

Were A' is an altitude of Godhra = 73 m= 0.073 km, and θ_z [fx]is zenith angle.

4. Economic analysis

Any conventional or non-conventional device value can be judged based on its economic viability. Annual operating cost and initial cost are two parts usually considered for the costing of any energy system. Economic analysis carried out for identifying the financial liability of the present scenario [2,34]. accomplish Techno-economic evaluation of domestic solar water heating systems in India. It represents an economic evaluation of DSWHS in India.

It is found that the PTC system with chrome reflector and copper coated receiver gives maximum efficiency. The economic analysis is carried out on the PTC system with a chrome reflector and a copper-coated receiver having automatic tracking, manual tracking and the same glass cover system.

4.1. Initial capital cost

Initial capital cost is estimated by adding all expenses made for building a system. The initial cost of (A) manual tracking system found as Rs.5330/- (INR). In (B) automatic tracking system Rs.1250/- (INR) add to the base price, and Rs.1760/- (INR) added to (C) glass cover system. Break up on initial capital cost for all three systems are listed in Table 3.

4.2. Annual costs

Annual costs of any process are defined as a ratio of the annual first cost to its annual output. To find the system's annual output, it is necessary to find the cost of water heating. The following process calculates it.

The energy needed to raise the 1 °C temperature of 1 kg of water = Heat Capacity of water = 4200 J/kg^{0}C and 1 J = 2.78 x 10^{-7} kWh.

Therefore, the power needed to raise the 1 °C temperature of 1 kg of water (E) = 4200 x 2.78 x 10^{-7} kWh

E = 1.1676 x 10^{-3} KWH

Conventional domestic water heating equipment is an electric geyser. So Cost of Energy required is converted in INR by adding the cost of electricity [34]. In Gujarat, India cost of 1 unit (kwh) is Rs 5.50/-(INR) as per Gujarat electricity distribution company say MGVCL considering all taxes [35].

E_{cost} = (1.1676 x 10^{-3}) x 5.50= Rs 0.0064218/- per kWh

Now, the annual cost of water heating (ACWH) using electricity can be estimated by the following equation.

$$ACWH = E_{cost} \times \Delta T \times \text{Annual hot water production} \tag{18}$$

Table 4
Annual cost of water heating per kg.

Cost (INR)	Manual Tracking	Automatic Tracking	Manual tracking with a Glass cover
Capital cost (P)	5330	6580	7090
Salvage Value (S) (10% of principal value)	533	658	709
Life of System (n) years	20	20	20
Interest rate (i) %	0.10	0.10	0.10
Capital Recovery Factor (CRF)	0.1	0.1	0.1
Sinking Fund Factor (SRF)	0.0	0.0	0.0
Annual First cost = (CRF*P)	565.4	698.0	752.1
Annual Salvage Value (SFF*P)	32.4	40.0	43.1
Annual Maintenance Cost (Rs. 0.15* Annual First Cost)	84.8	104.7	112.8
Annual First Cost/m^2= (Annual First Cost + Annual Maintenance Cost-Annual Salvage Value) x 0.66	407.8	503.4	542.4
The annual cost of water heating (ACWH)	1338.1	1364.2	1504.8
The annual cost of water heating per kg = Annual First Cost/annual cost of water heating (ACWH)	**0.3**	**0.4**	**0.4**

Table 5
Payback periods.

Cost (INR)	Manual Tracking	Automatic Tracking	Manual tracking with a Glass cover
Capital cost (P)	5330	6580	7090
Operating Cost	0	0	0
Annual Maintenance Cost (Rs. 0.15* Annual First Cost)	84.81	104.70	112.81
The annual cost of water heating (ACWH)	1338.06	1364.18	1504.82
Subsidized cost given by government sectors is taken as 4% (Capital cost * 0.04)	213.20	263.20	283.60
Net Profit = Annual Cost of water heating (ACWH) - operating cost-Maintenance Cost	1253.3	1259.5	1392.0
Payback period = (Investment - Subsidized cost)/(Net Profit)	**4.1**	**5.0**	**4.9**
Payback period (Without Subsidy) = (Investment)/(Net Profit)	**4.3**	**5.2**	**5.1**

Table 6
Reported efficiencies.

Sr	Date	Tracking	Efficiency(η_{exp})	η_{opt}	η_{theo}
1	12/3/2020	Manual	11.42	15.99	15.65
2	13/3/2020	Manual	12.23	15.99	15.82
3	12/3/2020	Automatic	15.77	15.99	15.37
4	13/3/2020	Automatic	14.11	15.99	15.91
5	12/3/2020	Glass cover manual	13.55	15.99	14.44
6	13/3/2020	Glass cover manual	13.44	15.99	15.70

Where ΔT is the temperature difference between input and output water temperature of the system. Here tank capacity is 30 L so, annual hot water production for 365 days predicted as 10950 L. The annual cost of water heating (ACWH) is listed in Table 4 for all three systems.

The annual cost of water heating per kg of all three systems is calculated [2]. Generally, it is calculated per meter square. The proposed novel PTC has an area of 0.66 square meters so, it is found by considering that factor. It is shown in Table 5.

4.3. Payback periods

The payback period is used frequently for judging the economic viability of a solar system. It is defined as a time taken for cumulative saving on energy or income become equal to the initial investment [2,26]. The operating cost of the proposed system is zero. It is shown in Table 6.

4.4. Carbon credit

Carbon Credit is a directorial methodology used to control greenhouse gasses by providing economic encouragements to reduce greenhouse gasses emissions. The progress of a carbon project that offers a drop-in Greenhouse Gas emissions is how participating entities may generate tradable carbon credits [36,37].

$E = 1.1676 \times 10^{-3}$ KWH

Table 7
CO_2 reduction.

Data	Manual Tracking	Automatic Tracking	Manual Tracking with a Glass cover
ΔT (°C)	19.0	19.4	21.4
Total energy saved/Day (kWh)	0.66	0.67	0.74
CO_2 reduction/day(kgCO_2e)	0.63	0.64	0.71
CO_2 Reduction/annum (kgCO_2e)	189.96	193.66	213.63
CO_2 Reduction/annum (tCO_2e)	0.18	0.19	0.21

$$\text{Total energy saved/Annum} = \text{E x } \Delta\text{T x Tank Capacityx300} \tag{19}$$

Here, Tank capacity is 30 L, and E is the power needed to increase the 1 °C temperature of 1 kg of water. 300 clear days are assumed for calculations where ΔT is the temperature difference of input water temperature to the system's output water temperature.

4.5. CO_2 reduction

For finding CO_2 Reduction, first, find total energy used or saved and calculate it with CO_2 reduction emission factor. The CO_2 emission reduction factor is calculated total production of CO_2 for producing any form of energy. For calculations, the Indian electricity CO_2 emission factor is taken as 0.950 [38]. suggested it by identifying hot spots and calculate the power generation of Indian power plants.

$$\text{Total } CO_2 \text{ Reduction} = 0.950 \text{ x Total Energy saved per annum kWh} \tag{20}$$

4.6. Carbon credit earned

Carbon emissions trading is a category of procedure that permits industries to purchase or trade government-granted allotments of carbon dioxide output. 40 countries and 20 municipalities use either carbon taxes or carbon emissions trading reported by the World Bank. European Union is one of them. Carbon dioxide emission reduction can be traded @ €21/tCO2e, European Climate Exchange [36,39,40]. The life cycle of proposed all three systems is 20 yrs. So we can calculate carbon credit eared by all three systems are as follows.

$$\text{Carbon Credit Earned by All Three Systems} = CO_2 \text{ Reduction /annum (tCO2e) x 21 x Euro to INR Rate} \tag{21}$$

For the calculations, Rs.82.57 (INR) is taken as currency exchange rate from EURO to INR.

5. Results and discussion

The development and design of novel PTC are unique. It can disassemble and can be easily transported from one place to another in a compact car. It can solve significant problems that occurred in the receiver joint. In this design receiver is stationary. Due to bearing arrangements, the trough structure can easily track. For automatic tracking, less effort is required. Simple 12 v low RPM DC motor can rotate Trough. Glass cover arrangement reduces heat losses accrued by wind effect. It can also reduce dust deposition on the reflector. By glass cover and closed trough, arrangement produces a greenhouse effect. A drawback of the glass cover is that it increases the trough's weight and restricts the trough's easy movement.

The experimental setup is installed at Godhra, Gujarat, India. Previously PTC was tested for various three reflectors and six receivers with manual tracking arrangements. Novel PTC is having features like attachments of the automatic tracking system and glass cover. So it is planned to test all components of the novel PTC. Three setups are developed for all three arrangements. For efficient results, all tests are repeated. The results of the tests are shown in Table 7. The average experimental efficiency of PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 11.83%, 13.50%, and 14.94 %, respectively. No significant difference recorded in theoretical efficiency.

Meteorological data like wind velocity, direct solar radiation and atmospheric temperatures are recorded and shown as graphs in figure no 6, 7, and 8, respectively.

A detailed economic analysis was carried out for all three proposed PTC systems. The annual cost of water heating (ACWH) for the PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 1338/-, 1509/- and 1364/- INR, respectively. The cost of water heating per kg has been just 0.3/- INR for the manual tracking PTC system. For Manual tracking with a Glass cover and Automatic tracking, it is equivalent to 0.4/- INR. The payback period is predicted for all three novels PTC a system. It is equal to 4 years for a PTC system for manual tracking. For PTC systems of Manual tracking with a Glass cover and Automatic tracking, it is found equivalent to 5 years.

Solar Energy is clean green energy. The use of solar energy reduces greenhouse gas production. Total CO_2 Reduction and total Energy saved are calculated for all three proposed systems, and it is shown in Table 8.

Table 8
Carbon credit earned.

Data	Manual Tracking	Automatic Tracking	Manual tracking with a Glass cover
CO_2 Reduction/Annum (tCO_2e)	0.18996	0.19367	0.21364
Carbon Credit Earned/Annum (INR)	329.38	335.81	370.43

Table 9
Uncertainty in experimental results.

Sr	Result	Symbol	% Uncertainty
1	Experimental Thermal efficiency	η_{exp}	1.49
2	Optical Thermal Efficiency	η_{opt}	00.00
3	Theoretical Thermal Heat Loss	U_L	2.46
4	Theoretical Efficiency	η_{theo}	2.88

Table 10
Uncertainty in equipment.

Sr. No.	Device name	Parameter	Symbol	Unit	Max. Value	Uncertainty
01	RTD, PT-100	Temperature	T	°C	-50 TO 400	0.01
02	Solarimeter	Intensity measurement	I	W/m^2	0 TO 2000	10
03	Anemometer	Wind velocity	V	m/s	0 TO 45	0.5

Solar saving can be earned by selling carbon credits. This earning can be used to reduce the payback period. Carbon credits earned by all three systems are shown in following Table 8. Solar saving by carbon credit earned is nearly the same as capital cost after 20 years as the proposed novel PTC system's lifespan is estimated to 20 years.

6. Uncertainty in results

Instrumental error and uncertainty in results affect the outcomes [41]. suggested methods to find uncertainty in experiments. Uncertainty analysis is executed, and obtained results are shown in Table 9. Uncertainty in Equipment is shown in Table 10.

7. Conclusions

This study evaluates newly designed PTC with three attachments. With results, it is proven that developed novel PTC is capable of producing low-temperature water heating. Due to novel arrangements, no flexible joint required for receiver joints and no water leakage problems accrued. Following points are concluded after analysis.

- ➢ The automatic tracking PTC system works excellent with the highest experimental efficiency of 15.77%, closest to theoretical efficiency.
- ➢ The average experimental efficiency of PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 11.83%, 13.50%, and 14.94 %, respectively.
- ➢ The average theoretical efficiency of PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 15.73%, 15.07%, and 15.64 %, respectively.
- ➢ Wind speed affects the efficiency of manual and automatic systems, but it is stable in manual tracking with the glass cover PTC system.
- ➢ The annual cost of water heating (ACWH) for the PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 1338/-, 1509/- and 1364/- INR, respectively.
- ➢ The cost of heating 1 kg of water is less than 0.50 paisa (INR). For manual tracking, the PTC system is only 0.3/- INR, and for Manual tracking with a Glass cover and Automatic tracking, it is equivalent to 0.4/- INR.
- ➢ Payback time for manual tracking PTC is 4.1 years considering subsidy when it is 4.3 years without considering subsidy. For PTC systems of Manual tracking with a Glass cover and Automatic tracking, it is found 5.2 years and 5.1 years without subsidy, respectively.
- ➢ CO_2 Reduction per annum (tCO_2e) for the PTC with Manual tracking, Manual tracking with a Glass cover and Automatic tracking is 0.189, 0.193 and 0.213, respectively.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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