Experimental Investigation on Double Concentrating Parabolic Solar Collectors

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***Abstract*—This Radiation Energy from the sun is one among the abundantly available non-conventional energy resources. Compared with wind energy, tidal energy...etc., solar energy has utmost potential. With this project an approach has been done to consume maximum Solar Radiation by introducing a Double Concentrating Solar parabolic Trough collector. The present study of this project work represents experimental analysis based on the design, development, and efficiency analysis of water heating by Double parabolic concentrating system using Metalized polyester film Concentrator. The efficiency of the concentrator is experimentally tested with water circulated as heat transfer fluid. The tests are conducted by placing and removing Second Concentrator in the Experimental Setup.**

***Index Terms*—Double Concentrating, solar collector, parabolic trough, solar radiation**

I. Introduction

Parabolic reflector are made of different materials like glass with back silver coating, Fe sheet, Al sheet, zn sheet etc.. glass mirror is brittle and chance of damage is very high. Fe sheet, Al sheet, zn sheet reflectors have strength but they will form oxide film, which reduces the concentrating efficiency. Cost and manufacturing techniques of metallic reflectors won't meet the low budget utilization. Making reflectors with PERT Film is one among the best materials for making concentric PARABOLIC collectors. It won't form oxide Layer. Also they are cheap, light weight and have long life.

Water is made to flow in the pipe either through natural flow or forced flow. Forced flow is created by using a pump. Natural flow is also called Thermosyphon system. The principle Thermosyphon procedure is that cold water has a more specific density than warm water and so being heavier will sink down. For this region, the collector is always attached beneath the water storage tank, so that cold water from the tank reaches the collector through descending water pipe. If the collector heats up the water, the water rises once again and reaches the tank by way of an ascending water pipe at the upper end of the collector. The cycle of the tank, water pipe, collector ensures the water is heated up until it achieves an equilibrium temperature. The consumption of warm water can be done at the top of the tank. Water in the tank can be replaced at the bottom of the tank. The collector the heats the cold water once again.

Due to greater temperature change at higher solar irradiances, warm water increases faster than it does at lower irradiance. A Thermosyphon system's storage tank need to be put good above the collector, or else the flow become reverse during the night and all the water will cool down. Furthermore, the flow doesn't work adequately at very small height differences. In location with excessive solar irradiation and flat roofs, storage tanks are quite often set up on the roof. Thermosyphon system is not suitable for large system, i.e. 10m2 of collector surface. Further it is difficult to place the tank above the collector in buildings with sloping roofs and single –circuit Thermosyphon systems are only suitable for frost- free regions.

II. PROPERTIES OF METALIZED POLYESTER FILM

Chemical properties:

S.No	Chemicals	Poor	Fair	Good
1	Acids (concentrated)			✓
2	Acids (diluted)			✓
3	Alkalis	✓		
4	Aromatic hydrocarbons		✓	
5	Greases and Oils			✓
6	Halogens			✓
7	Ketons			✓
8	Alcohols			✓

Table 1: Chemical Resistance

Mechanical properties**:**

S.No	Property	
1	Coeffici ent of fric tion	0.2 – 0.4
2	Hardness- Rockwell	M 9 4 – 1 0 1
3	I z o d Impact strength	13-35
4	Poission's Ratio	0.37 – 0.44
5	Tensile strength	80Mpa

Table 2: Mechanical Properties

Physical properties:

S.No	Property	
1	D e n s I t y	1.3 – 1.4 g/cm^3
2	F l a m m a b I l I t y	Self - Extinguishing
3	Limiting oxygen Index	21
4	Refractive Index	1.58 – 1.64
5	Resistance to ultra - violet	good
6	Water absorption – equilibrium	<0.7 %
7	W a t e r a b s o r p t I o n – over 2 4 hours	0.1%

Table 3: Physical properties

Thermal properties:

S.No	Property	
1	Coefficient of thermal expansion	20-30 x 10^{-6}/K
2	Heat deflection temperature at 0.4M p a	115ºC
3	Heat deflection at temperature at 1.8 M p a	8 0 ºC
4	L o w e r w o r k I n g t e m p e r a t u r e	-40 to -60ºC
5	S p e c I f I c h e a t	1 2 0 0 - 1 3 5 0 J / (K. K g)
6	T h e r m a l c o n d u c t I v I t y at 23 º C	0.15-0.04
7	Upper worKing temperature	115-170

Table 4: Thermal properties

III METHODOLOGY

Solar Constant (Gsc): It is the R a d I a t I o n R e c e I v e d p e r s q u a r e m e t e r o f t h e a t m o s p h e r e a t I n c I d e n c e a n g l e θ = 0 w h e n t h e e a r t h I s a t t h e m e a n d is t a n c e f r o m t h e s u n.

Gsc = 1367 W/m2

- Gsc, is a mean value
- The distance between the sun and earth varies by 3.3%

Solar Irradiation (Gon): Exact Irradiation incident on a surface of θ = 0 just outside the atmosphere. It is calculated using S o l a r c o n s t a n t. It varies +/- 45 W / m ^{2} over the year.

E x t r a t e r r e s t r I a l Radiation (Go): It is the radiation incident on the surface tangent to the outer surface of the atmosphere. It is the function of Zenith angle θz. so it depends on Latitude , Time during the day and the deflection.

B e a m R a d I a t I o n (G_{cb}): Solar rays which reaches the ground without changing the direction from the earth surface.

Diffuse Radiation (Gcd): Solar rays reaching the ground after a change in the direction by particles in the Atmosphere

Reflected Radiation: It is the Solar rays Reflected from the surrounding.

Declination (δ): It is the angle made between the plane of the equator and the line joining the two centers of the earth and the sun.

$$\delta \approx 23.45 * \sin(360 * (284+n)/365)$$

Declination Varies between -23.45o ≤ δ ≤ + 23.45o

Hour Angle (ω): It is the angular displacement of the sun east or west of the local meridian due to rotation of earth on its axis at 15^0 per hour. ω = 0 at solar noon and is recKoned negative in the forenoon and positive in the afternoon.

LATITUDE (φ): It is the angular distance, in degrees, minutes and seconds of a point North or South of the Equator. Sontyam (Experimental zone) Latitude: 170.42' N

LONGITUDE (L): It is the angular distance, in degrees, minutes and seconds of a point East or West of the Prime (Greenwich) Meridian. Sontyam (Experimental zone) Longitude: 830.18' E

ZENITH ANGLE (θZ): It is the angle between the zenith and the center of the sun's disc. The solar elevation angle is the altitude of the sun, the angle between the horizon and the center of the sun's disc. It depends on Latitude , Time during the day and the deflection.

ALTITUDE (A): The height above sea level of a location, in geographical location is called altitude.

S.No	Time	Hour angle , ω
1.	7:00 Am	75
2.	7:30 Am	67.5
3.	8:00 Am	60
4.	8:30 Am	52.5
5.	9:00 Am	45
6.	9:30 Am	37.5
7.	10:00 Am	30
8.	10:30 Am	22.5
9.	11:00 Am	15
10.	11:30 Am	7.5
11.	12:00 Am	0
12.	12:30 Am	7.5
13.	1:00 Pm	15
14.	1:30 Pm	22.5
15.	2:00 Pm	30
16.	2:30 Pm	37.5
17.	3:00 Pm	45
18.	3:30 Pm	52.5
19.	4:00 Pm	60
20.	4:30 Pm	67.5

Table 5: Hour Angle

Altitude, (A) = 0.079 Kilo meters at Sontyam (Experimental Location)

IV LITERATURE REVIEW

The vast use of concentric solar collectors leads to significant amount of research over the years in the field of water worming and steam production. The idea behind the setup is to minimize the heat losses associated with solar collection. It is fascinating to provide energy at better temperatures than those possible with flat plate solar collectors. In this Model, a "parabolic mirror" concentrates incident solar beam radiation onto a much smaller receiver area, greatly decreasing heat loses and maximizing the available energy from sun. Efficiency of concentrating parabolic collectors can be improved through absorber coatings, solar tracking and using external films.

W.W. COBLENTZ, C.W. HUGHES [12] absorptive and reflective properties of matter there is reason for believing that there is not any marked change in the low temperature emissive properties of the nonmetallic substances that are suitable for paints.

Martin Andritschky [18] absorber coatings can improve the efficiency of the solar water heater. Black paints can improve heat absorption Absorptivity is 50 – 93% and emissivity is 40 – 80%.

D. Sarma, R. gogoi, B.Nath, S.Konwar, C.L. Meitei [5] Experimental study of the designed and constructed flat plate solar water heater specifically for the region of jorhat, assam on latitude 26.75oN where the usual solar insolation is rather low compared to the other regions of India. From the day to day evaluation of the approach it suggests that the temperature varies and reach highest around the mid-day when the cooler plate receives maximum energy and is relatively low in the morning. The temperature of the water in the system depends on the climatic condition of the location. The efficiency of the system can be improved by proper coatings to the absorber.

Pradeep Kumar K V, Srikanth T, Venkatesh Reddy [6] considering the analysis with recognize to the optical and energy conversion efficiency. To ensure excellent performance and long technical existence, the solar reflectance of the reflector must be long term steady. For solar parabolic trough frame, a finite element model had been developed and used to determine the capability of the structure to assess the capability of the structure to absorb torsion and bending forces, under dead and wind loads. The fundamental hypothesis was that the use of long lasting, mild weight, low cost reflectors for growing the concentrator efficiency.

V CONSTRUCTION

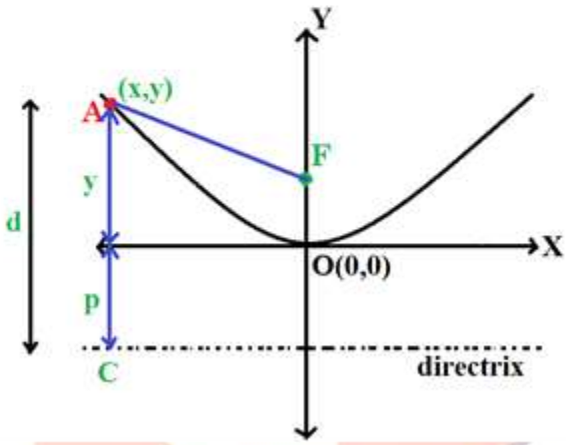

Fig.1 Parabola

First Parabola:
$x^2 = 24y$
Width of the parabola trough = 24 Inch = 0.6096 Meters
Height of the parabola trough = 06 Inch = 0.1524 Meters
Length of the parabola trough = 24 Inch = 0.6096 Meters
Area of the plane receiving radiation = 0.2716 Meter^2
Concentrating Ratio, C = Aa/Ar = 6.8525

Second Parabola:
$x^2 = 9.2y$
Arc length of parabola: (((p+q)/t) + t (ln(p+q)/t)) = 6.98 Inches
t =2P =4.72 Inches
Width of the parabola trough = 2.36 Inch = 0.05 Meters
Height of the parabola trough = 2.36 Inch = 0.05 Meters
Length of the parabola trough = 24 Inch= 0.6096 Meters
Area of the plane receiving radiation = 0.03 Meter^2

Mirror Surface:
Metalized Polyester Film- 0.07mm thickness
Parabola concentrator, depron and aluminum sheet.
Absorber:
Copper pipe- 15.87 mm dia
Thermal Conductivity of Copper = 399 W/mk
Length of copper pipe = 2 feet = 0.6096 m

Water Tank:
Plastic container having 20 liters Capacity

Other Material:
Plastic pipes - 16 mm diameter

Temperature Measuring Device:
Fluke Infrared thermometer 59 mini
Range: -18oc to 275oc
8:1 optics @ 90% energy
Laser Sighting

Fig.2 Parabolic Trough Second concentrator

Fig.3 Two concentrators Arrangement

Fig.4 Experimental setup, single concentrator

Fig.5 Experimental setup, double concentrator

- The Experimental set up is made of Card board and a plastic sheet.
- depron sheet has flexible nature. It can be easily folded in the form of a parabola.
- A Film (metalized polyester film) is attached on the parabola to reflect the solar beam radiation.
- Absorber is placed at the focal position to absorb heat. Absorber is coated with black enamel paint to enhance the heat absorption.
- The entire Experimental setup is insulated as shown in the above figures.
- A mechanism is provided for tracking and to arrest the tracking.
- IR Thermometer gives the temperature of input and output temperature of water entering the absorber.
- Heated water moves up due to density difference and stored in the water tank. High density cold water enters into the absorber.
- This experimental setup can be used to test the efficiency of collector in Single concentrator, Double Concentrators

VI RESULTS & DISCUSSIONS

I MODE : single concentrator
Date : 4th July, 2017
n = 185
Wind speed = 6.43 m/s

Time	TA (oC)	T i (oC)	T o (oC)	ΔT (oC)	Q2 (W/m^2)
9:30	26.4	23.4	26.6	3.2	264192
10:30	29.7	26.8	30.8	4	330240
11:30	35.1	31.3	35.9	4.6	379776
12:30	41.2	36.2	41.9	5.7	470592
1:30	49.8	43.8	50.2	6.4	528384
2:30	55.1	51.6	55.5	3.9	321984
3:30	57.9	53.2	58.4	5.2	429312

Table 7: Experimental Readings single concentrator

Q_2 = $20 * 4.182 * 1000 * 3.2$
= 267648 Joule

Avg. Q_2 = $(\Sigma Q_2) / 7$
= (264192 + 330240 + 379776 + 470592 + 528384 + 321984 + 429312) / 7
= 389211.4286 Joule

G_{on} = $1367\{1+0.033(\cos \frac{360*185}{365})\}$ W/m^2
= $1321.93 W/m^2$

δ ≈ $23.45 * \sin(360 * (284 + 185)/365)$
= 21.59^0

Cos θz = $(\cos 17.42 * \cos 21.59 * \cos 37.5) + (\sin 17.42 * \sin 21.59)$
= 0.814

G_o = $G_{on} * (\text{Cos } 0.814)$ W/m^2
= $1075.834 W/m^2$

a_1 = $0.95 * (0.5055 + 0.00595 * (6.5 - 0.079)^2)$
= 0.735

a_o = $0.98 * (0.4237 - 0.00821 * (6-0.079)^2)$
= 0.129

K = $1.02 * (0.2711 + 0.01858 * (2.5 - 0.079)^2)$
= 0.387

Transmittance for beam Radiation,

λ_b = $0.129 + 0.735 * e^{(-0.387/\cos 0.859277457)}$
= 0.597479389

G_{cb} = $\lambda_b * G_o$
= $0.597 * 1075.834$
= $642.273 W/m^2$

λ_d = $0.271 - 0.294 * 0.597479389$
= 0.09534106S

G_{cd} = $\lambda_d * G_o$
= $0.09534106 * 1075.834$
= $106.184 W/m^2$

Gc = $G_{cb} + G_{cd}$
= 642.273 + 106.184
= $748.457\ W/m^2$

Time	Q1 = Gcb (w/m²)	Gcd (w/m²)	Gc (w/m²)	Go (w/m²)	Gon (w/m²)
9:30	642.27	106.18	748.45	1075.83	1321.93
10:30	733.63	121.28	854.92	1228.86	1321.93
11:30	780.96	129.11	910.07	1308.14	1321.93
12:30	780.96	129.11	910.07	1308.14	1321.93
1:30	733.63	121.28	854.92	1228.86	1321.93
2:30	642.27	106.18	748.45	1075.83	1321.93
3:30	513.03	84.81	597.85	859.35	1321.93

Table 8: Calculated Solar Radiation - 4th July, 2017

Average Beam Radiation (Avg.Gcb) =
(642.273+733.635+780.961+780.961+733.635+642.273+513.036) / 7 $=689.53\ w/m^2$

Σ Input Q1 = 6457276.185 J
Σ Output Q2 = 389211.42 J
Efficiency, = Output energy/ Input energy
= 0.060274862 ⇒ 6.02**%**

II	**MODE**	:	Double Concentrator
	Date	:	5th July, 2017
	n	=	186
	Wind speed	=	6.69 m/s

Time	TA (oC)	T i (oC)	T o (oC)	ΔT (oC)	Q2 (W/m^2)
9:30	27	22.5	27.2	4.7	388032
10:30	33.5	24.6	33.8	9.2	759552
11:30	37.4	34.3	37.9	3.6	297216
12:30	42.8	39.7	43.2	3.5	288960
1:30	52.5	41.8	52.9	11.1	916416
2:30	57.7	53.1	57.9	4.8	396288
3:30	53.1	52.9	54.3	1.4	115584

Table 9: Experimental Readings double concentrator

Q_2 = $20 * 4.182 * 1000 * 4.7$

= 393108 Joule

Avg. Q_2 = $(\Sigma Q_2) / 7$

= (388032+759552+297216+288960+916416+396288+115584) / 7

= 451721.14 Joule

G_{on} = $1367\{1+0.033(\cos \frac{360*186}{365})\}$ W/m^2

= $1321.97 W/m^2$

δ ≈ $23.45 * \sin(360 * (284 + 186)/365)$

= 21.75^0

Cos θz = $(\cos 17.42 * \cos 21.75 * \cos 37.5) +$

$(\sin 17.42 * \sin 21.26)$

= 0.811

G_o = $G_{on} * (\text{Cos } 0.811)\ W/m^2$

= $1075.74\ W/m^2$

a_1 = $0.95*(0.5055+0.00595*(6.50.079)^2)$

= 0.735

a_o = $0.98 * (0.4237 – 0.00821*(6-0.079)^2)$

= 0.129

k = $1.02 * (0.2711 + 0.01858 * (2.5 – 0.079)^2)$

= 0.387

λ_b = $0.129 + 0.735 * e^{(-0.387/\cos 0.813869669)}$

= 0.58585424

G_{cb} = $\lambda_b * G_o$

= 0.597 * 1075.74

= 642.219 W/m^2

λ_d = 0.271 – 0.294 * 0.585

= 0.098

G_{cd} = $\lambda_d * G_o$

= 0.098758854 * 1075.74

= 106.175 W/m^2

G_c = $G_{cb} + G_{cd}$

= 642.219 + 106.175

= 748.394W/m^2

Time	Q1 = Gcb (w/m^2)	Gcd (w/m^2)	Gc (w/m^2)	Go (w/m^2)	Gon (w/m^2)
9:30	642.21	106.17	748.39	1075.74	1321.9
10:30	733.48	121.26	854.74	1228.61	1321.9
11:30	780.75	129.07	909.83	1307.79	1321.9
12:30	780.75	129.07	909.83	1307.79	1321.9
1:30	733.48	121.26	854.74	1228.61	1321.9
2:30	642.21	106.17	748.39	1075.74	1321.9
3:30	513.12	84.83	597.95	859.50	1321.9

Table 10: Calculated Solar Radiation - 27th May, 2017

Average Beam Radiation (Avg.Gcb)

= (642.219+733.481+780.755+780.755+733.481+642.219+513.123) / 7

= 6456284.873w/m2

Σ Input Q1 = 6456284.873Joule

Σ Output Q2 = 451721.1429Joule

Efficiency, η = Output energy/ Input energy

= 6.99% ==> 0.699

The declination of earth is shown from March, 2017 to June, 2017 as it was observed as -7.53 to 23.31 degrees at 79 meters Altitude, Location is Sontyam, Visakhapatnam

Date	Declination (δ)
3-Mar	-7.53
4-Mar	-7.15
6-Mar	5.98
8-Apr	6.76
10-Apr	7.53

8-May	16.96
9-May	17.24
10-May	17.51
26-May	21.09
27-May	21.26
28-May	21.43
13-Jun	23.21
14-Jun	23.26
15-Jun	23.31
4-July	21.59
5-July	21.75

Table.11: Day wise Deflections

Date	**Solar constant (Gsc) W/m2**	**Average Beam Radiation (W/m^2)**	**Average Diffuse Radiation (W/m^2)**	**Average Total Radiation on ground (W/m^2)**
3-Mar	1367	620.597	109.200	729.798
4-Mar	1367	623.2861	109.287	732.573
6-Apr	1367	688.759	110.785	799.544
8-Apr	1367	690.886	110.785	801.671
10-Apr	1367	693.120	110.791	803.917
8-May	1367	703.980	110.086	814.066
9-May	1367	703.806	110.042	813.849
10-May	1367	703.693	110.002	813.696
26-May	1367	753.186	111.453	864.640
27-May	1367	699.615	109.305	808.920
28-May	1367	699.280	109.265	808.545
13-Jun	1367	695.297	108.787	804.084
14-Jun	1367	695.104	108.758	803.862
15-Jun	1367	694.890	108.735	803.626
4-July	1367	689.539	113.998	803.537
5-July	1367	689.433	113.981	803.414

Table 12: Solar Radiation

This study dealt with the design, construction and Efficiency analysis of the concentric parabolic trough Water heater.from the experimental study of the Designed prototype as shown in the figures above it was compared the efficiencies of mode1, 2.

From the Experimental readings, The maximum out put temperature obtained from the prototype for Single concentrator (Mode-I) on 4th July, 2017 is 58.9oC.

The maximum out put temperature obtained from the prototype for double concentrator (Mode-II) on 5th July, 2017 is 57.9oC. Ambient Temperature at the time of taking readings is between 32oC to 39oC.

Hourly variation of radiation with respect to time is shown in the Fig. above. Hourly Variation of total solar radiation is in the range of 803.537W/m2, 803.414W/m2 respectively.

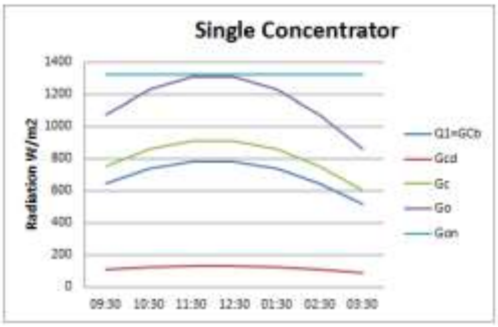

Fig.6 Hourly Solar Radiation Graph, 4th July 2017

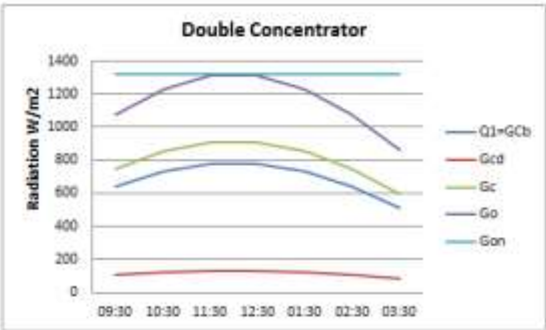

Fig.7. Temperatures Graph

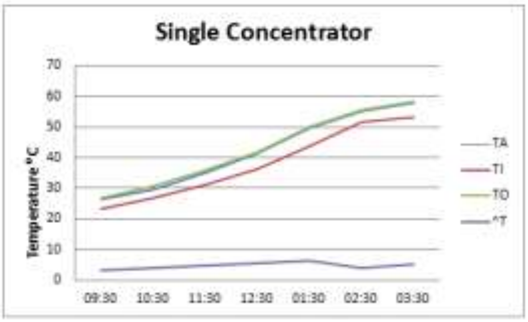

Fig.8. Temperatures Graph

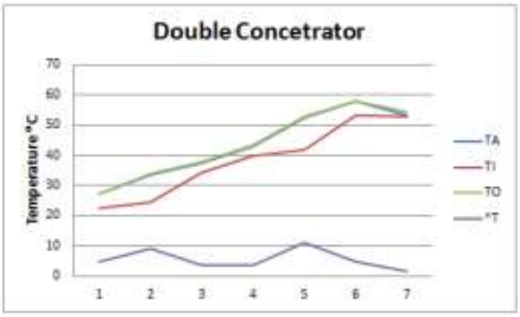

Fig.9 Hourly Solar Radiation Graph, 5th July 2017

VI CONCLUSION

The experiment has been carried on the experimental setup with proper insulation.

The solar concentrator made with plastic film is cheaper than the concentrator made with metals like stainless steel, aluminum and zinc etc.,

Based on the graphs from March, 2017 to July, 2017, the following results have been observed with reference to the graph,

- The efficiency in single concentrator is 5.9 to 9.3 %
- The efficiency of double Concentrator is 6.5 to 11.1%

Due to the difference in climatic stipulations, the efficiency varied from time to time.

Due to the shadow of second concentrator portion, the efficiency is getting decreased. In this Experimental setup we observed a variation of 0.87- 1.78 percent efficiency increased after adding second concentrator.

The main research fields for this work are Material economy, Energy cost saving and pollution control.

VII FUTURE SCOPE

1. Optical Design and Development of Metalized polyester film Double Solar Concentrator for Steam production and photovoltaic for commercial and non-commercial usage.

2. Double Parabolic Trough collectors can be analyzed with several types of operation fluids as a working fluid in both Active and passive modes.

3. Design and Development of a new trough, possibly made from composite materials, to make lighter, Anti-corrosive and more durable.

4. Parallel to the experimental work, a numerical analysis is used to investigate and estimate the solar radiation at the Experiment conducting Location.

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