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Experimental Investigation on Concentrating Parabolic Solar Collectors at 170.42’ N Latitude & 830.18’ E Longitude

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ABSTRACT:
Solar Energy is one among the abundantly available renewable 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 Radia tion by introducing a 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 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 varying the position in Non-Tracking, Tracking and Extended films of parabolic trough collector.

Key Words: **Metalized polyester film, solar colle ctor, parabolic trough, solar radiation, Tracking, Non- Tracking and Extended films.**

NOMENCLATURE

Aa	-	Area of the Absorber
Ar	-	Area of the Receiver
G_{sc}	-	Solar Constant
G_{on}	-	Solar Irradiation
G_o	-	Extraterrestrial Radiation
G_{cb}	-	Beam Radiation
G_{cd}	-	Diffuse Radiation
Gc	-	Beam Radiation + Diffuse Radiation
δ	-	Declination
ω	-	Hour Angle
φ	-	Latitude
L	-	Longitude
θ_Z	-	Zenith angle
A	-	Altitude
C	-	Concentration Ratio
T_A	-	Absorber Temperature
T_i	-	Input water temperature into the Absorber
T_o	-	Output water temperature from the Absorber
M	-	Mass of water
C_p	-	Specific Heat
ΔT	-	Difference in temperature
Tamb	-	Ambient Temperature

Introduction:
Concentrating solar water heaters are more complicated to construct and more expensive, however they are very efficient. The main thing in concentrated solar water heating or boiling is the use of mirrors as other reflective surfaces to construct the sun’s rays hitting a large area onto a tube or concentrator full of a fluid which is heated. The overall idea is magnifying and concentrating the solar radiation incident upon a large area (concentrating mirror) onto a small volume (absorber pipe).

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Parabolic reflector are made of different materials like glass, steel sheet, aluminum sheet, zinc sheet etc.. glass is brittle and chance of breakage is very high. Metallic reflectors have strength but they will form oxide film, which reduces the optical efficiency. Cost and manufacturing techniques of metallic reflectors won't meet the domestic utilization. Making reflectors with Metalized Polyester Film is one among the best materials for making concentric collectors. It won't form oxide film. Also they are cheap, light weight and have long life.

Mayur G Tayade, R E Thombre, SubrotoDutt [1] the performance of a new parabolic trough collector with hot water generation is investigated through experiments over one full day in winter period. The maximum value of each of those parameters is observed around noon, when the incident beam radiation is at its peak. The fabrication and design of a solar parabolic trough using locally available materials is possible hence low temperature trough will be a better solar thermal device for the rural and remote area. This research has its own special features maintenance cost is minimum and hence economical, running cost is nil.

ARUNACHALA U.C [2] the compound parabolic trough cooker is tested for six consecutive days. The maximum oil temperature is noted to be 110oC. During off- sunshine hours, the oil temperature drop was around 35oC. As a result to inclement weather and inherent limitations, the system couldn't attain maximum efficiency. During afternoon, oil temperature rise is sufficient to cook rice and the oil temperature during last evening is sufficient for warmingOkoronkwo

S. Sadhishkumar, T.Balusamy [3] A single phase closed thermosyphon has been fabricated and experimented to utilize solar energy for water heating. The working fluid moves as a result of density gradient caused by temperature differences. This work was achieved using flat plate collector. Performance parameters such as instantaneous collector efficiency and heat removal factor are calculated.

C.A, Nwufo, O.C, Ogueke, N.V [4] Performance evolution of a thermosyphon water heating system using a compound parabolic solar collector is presented. The cold water stored in the upper tank flows by gravity through a pipe passing through the focus of a parabolic collector into a lagged tank where it is stored for usage. Results obtained showed that the thermosyphon system can produce domestic heating water of temperature of about 90^{o}C.

Construction:

The Experimental set up is made of Card board and a plastic sheet. Plastic 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 below 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 Non- Tracking mode, Tracking mode and Extended films at the ends.

DIMENSIONS FOR MAKING TROUGH:

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

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(i) (ii) (iii)

Fig. 1 Experimental set up of solar concentrating collector

EXPERIMENT PROCESS

The experiment procedure was started by filling with 30 liters of water in the water tank. Necessary care should be taken to avoid external temperature disturbances duly providing proper insulation. All the pipe joint points for leakages should be inspected thoroughly. Cold water from the storage tank entered into the absorber tube through insulated plastic pipe. The water tank was located above the level of collector to ensure that the flow is to be natural. The water in the absorber tube which was located at focal axis of the parabolic trough was heated by the concentrated solar energy.

As the density of hot water is less than the cold water, the heated water flows automatically to the top of the tank and the same will be replaced by the cold water from the bottom of the tank. The data of all readings at ambient temperature, fluid temperatures (Input, output temperature of the absorber), and beam solar radiation were collected.

The experiment was performed for 7 hours over the day from 8.30 AM to 3.30 PM and the experiment has been performed in three modes viz., the average angular displacement in tracking mode is almost 1^oper 4 minutes.

(i) Non Tracking Mode with East-west direction,
(ii) Tracking mode (Manual) with North-South direction,
(iii) Extended films on the parabola with East – West direction.

The beam radiation focused on the trough plane was calculated and considered as in-put energy. The temperatures which were taken from the experiment had been decided the output energy. Efficiency was calculated based on the input and output calculations.

<u>Solar Constant</u> (G_{sc}) = 1367 W/m^2

<u>Solar Irradiation</u>$G_{on} = G_{sc}\{1+0.033(\cos\frac{360*n}{365})\}$ W/m^2

<u>Extraterrestrial Radiation</u>$G_o = G_{on} * (\text{Cos } \theta z)$ W/m^2

$\text{Cos } \theta z = \cos\varphi * \cos\delta * \cos\omega + \sin\varphi * \sin\delta$

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

<u>Beam Radiation</u> $G_{cb} = \lambda_b * G_o$

$\lambda_b = a_o + a_1 * e^{(-k/\cos\theta z)}$

$a_o = r_o * (0.4237 - 0.00821 * (6\text{-}A)^2)$

$a_1 = r_1 * (0.5055 + 0.00595 * (6.5 - A)^2)$

$k = r_k * (0.2711 + 0.01858 * (2.5 - A)^2)$

At Tropical Climate Zone r_o =0.95, r_1 = 0.98, r_k = 1.02

<u>Diffuse Radiation</u>$G_{cd} = \lambda_d * G_o$

$\lambda_d = 0.271 - 0.294 * \lambda_b$

<u>TOTAL Radiation (Gc)</u> = $G_{cb} + G_{cd}$

EFFICIENCY OF THE SOLAR COLLECTOR

In - put = (Avg.Gcb of the day) * 3600 * 7 * Area of the concentrator plane

=(Avg.Gcb of the day) * 3600 * 7 * 0.37161216

=(Avg.Gcb of the day) * 9364.626432

Out-put = $M * C_P * \Delta T$

= 30 * 4182 * 1000 * ΔT, (C_p= 4182J/Kg K)

= 125460 * ΔT

$$\text{Efficiency} = \frac{Avg.Output\ \ energy}{Input\ \ energy}$$

CALCULATIONS

I	**MODE**	:	NON – TRACKING
	Date	:	26th May, 2016
	n	=	146
	Wind speed	=	5.59 m/s

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S.No	Time	TA (°C)	T i (°C)	T o (°C)	ΔT (°C)	Q2 (W/m²)
1	9:30	45.1	35.1	40.8	5.7	715122
2	10:30	51.3	38.8	49.2	10.4	1304784
3	11:30	52.7	40.2	51.7	11.5	1442790
4	12:30	53.2	43.3	52.4	9.1	1141686
5	1:30	58.1	45.8	55.6	9.8	1229508
6	2:30	61.2	44.4	59.9	15.5	1944630
7	3:30	66.6	44.6	62.2	17.6	2208096

Table:1 Experimental Readings NON – TRACKING

Q_2= 30 * 4.182 * 1000 * 5.7 =715122 Joule

Avg. Q_2 = (Σ Q_2) / 7

= (715122 + 1304784 + 1442790 + 1141686 + 1229508 + 1944630 + 2208096) / 7

= 7053309.97 Joule

G_{on} = $1367\{1+0.033(\cos\frac{360*146}{365})\}$ W/m^2

= 1330.505201 W/m^2

δ ≈ 23.45 * sin (360 *(284 + 146)/365) = 21.09^0

Cos θz= (cos 17.42 *cos21.09*cos 37.5) + (sin 17.42 * sin 21.09) = 0.859277457

G_o = G_{on} * (Cos 0.859277457) W/m^2 = 1143.273126 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}= λ_{b*} G_o = 0.597479389 *1143.273126 = 683.0821285 W/m^2

λ_d= 0.271 – 0.294 *0.597479389= 0.09534106S

G_{cd}= λ_{d*} G_o=0.09534106 * 1143.273126 = 109.0008714 W/m^2

Gc = G_{cb} +G_{cd} =683.0821285 + 109.0008714 = 792.0829999 W/m^2

Time	Q1 = Gcb (w/m²)	Gcd (w/m²)	Gc (w/m²)	Go (w/m²)	Gon (w/m²)
9:30	683.082	109.000	792.082	1143.273	1330.505
10:30	817.079	114.185	931.264	1307.774	1330.505
11:30	887.154	116.676	1003.83	1392.987	1330.505
12:30	887.154	116.6761	1003.83	1392.987	1330.505
1:30	817.079	114.1856	931.264	1307.774	1330.505
2:30	683.082	109.000	792.082	1143.273	1330.505
3:30	497.672	100.450	598.123	910.575	1330.505

Table:2 Calculated Solar Radiation - 26th May, 2016

Average Beam Radiation (Avg.Gcb) =(683.0821285 + 817.079151 + 887.1549703 + 887.1549703 + 817.079151 + 683.0821285 + 497.6728239) =753.1864748w/m^2

Σ Input Q1 = 7053309.97 J

Σ Output Q2 = 1426659 J

Efficiency, η = Output energy/ Input energy = 0.202268075 i.e., 20.22%

II MODE : TRACKING

Date : 27th May, 2016

n = 147

Wind speed = 5.59 m/s

S.No	Time	TA (°C)	T i (°C)	T o (°C)	ΔT (°C)	Q2 (W/m²)
1	9:30	49.3	35.8	47.2	11.4	1430244
2	10:30	55.9	37.8	53	15.2	1906992
3	11:30	57.4	41.2	55.2	14	1756440
4	12:30	63.7	41.3	59.2	17.9	2245734
5	1:30	65.9	42.8	62.8	20	2509200
6	2:30	72.4	45.9	68.3	22.4	2810304
7	3:30	76.2	48.1	74.8	26.7	3349782

Table:3 Experimental Readings TRACKING

Q_2= 30 * 4.182 * 1000 * 11.4 =1430244 Joule

Avg. Q_2= (Σ Q_2) / 7

= (1430244 + 1906992 + 1756440 + 2245734 + 2509200 + 2810304 + 3349782) / 7

= 6551637.072 Joule

G_{on} = $1367\{1+0.033(\cos\frac{360*147}{365})\}$ W/m^2

= 1330.505201 W/m^2

δ ≈ 23.45 * sin (360 *(284 + 147)/365) = 21.26^0

Cos θz= (cos 17.42 *cos21.26*cos 37.5) + (sin 17.42 * sin 21.26) = 0.813869669

G_o = G_{on} * (Cos 0.813869669) W/m^2 = 1082.490683 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*$e^{(-0.387/\cos 0.813869669)}$ = 0.58585424

G_{cb}= λ_{b*} G_o = 0.597479389 *1082.490683 = 634.1817562 W/m^2

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λ_d= 0.271 – 0.294 * 0.58585424 = 0.098758854
G_{cd}= λ_{d*} **G_o**=0.098758854 * 1082.490683= 106.9055388 W/m^2
Gc = **G_{cb}** **+G_{cd}** =634.1817562 + 106.9055388 = 741.087295W/m^2

Time	Q1 = Gcb (w/m²)	Gcd (w/m²)	Gc (w/m²)	Go (w/m²)	Gon (w/m²)
9:30	634.181	106.905	741.087	1082.490	1330.054
10:30	759.135	111.991	871.1272	1236.818	1330.054
11:30	824.536	114.428	938.9651	1316.760	1330.054
12:30	824.536	114.428	938.9651	1316.760	1330.054
1:30	759.135	111.991	871.1272	1236.8180	1330.054
2:30	634.181	106.905	741.087	1082.4906	1330.054
3:30	461.600	98.4837	560.084	864.18541	1330.054

Table:4 Calculated Solar Radiation - 27th May, 2016

Average Beam Radiation (Avg.Gcb) =
(634.1817562 + 759.135278 + 824.5367995 + 824.5367995 + 759.135278 + 634.1817562 + 461.6002862) =699.6154219 w/m^2

Σ Input Q1 = 6551637.072 Joule
Σ Output Q2 = 2286956.571 Joule
Efficiency, η = Output energy/ Input energy = 0.349066431 i.e., 34.90%

III MODE : EXTENDED FILMS
Date : 28th May, 2016
n = 148
Wind speed = 5.59 m/s

S.No	Time	TA (°C)	T i (°C)	T o (°C)	ΔT (°C)	Q2 (W/m²)
1	9:30	44.4	36.9	41.1	4.2	526932
2	10:30	48.9	37.5	46.9	9.4	1179324
3	11:30	52.6	39.4	49.7	10.3	1292238
4	12:30	59.8	44.5	55.2	10.7	1342422
5	1:30	64.1	43.5	60.4	16.9	2120274
6	2:30	72.5	46.7	68.1	21.4	2684844
7	3:30	73.8	48.3	71.4	23.1	2898126

Table:5 Experimental Readings Extended film

Q_2= 30 * 4.182 * 1000 * 4.2 = 526932 Joule
Avg. Q_2 = (Σ Q_2) / 7
= (526932+1179324+1292238+1342422+2120274+2684844+2898126) / 7
= 1720594.286 Joule

G_{on} = 1367{1+0.033(cos$\frac{360*148}{365}$)} W/m^2 = 1329.616514 W/m^2
δ ≈ 23.45 * sin (360 *(284 + 148)/365) = 21.43^0
Cos θz = (cos 17.42 *cos21.43 *cos 37.5) + (sin 17.42 * sin 21.43) = 0.813845203
G_o= 1329.616514 * (Cos 0.813845203) = 1082.102022 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$^{(-0.387/\cos 0.813845203)}$ = 0.585847709

G_{cb}= **λ_{b*}** **G_o** = 0.585847709 *1082.102022 = 633.9469905 W/m^2
λ_d= 0.271 – 0.294 *0.585847709 = 0.098760774
G_{cd}= **λ_{d*} G_o**=0.09534106 * 1082.102022= 106.8692327 W/m^2
Gc = **G_{cb}** **+G_{cd}** =633.9469905 + 106.8692327 = 740.8162232 W/m^2

Time	Q1 = Gcb (w/m²)	Gcd (w/m²)	Gc (w/m²)	Go (w/m²)	Gon (w/m²)
9:30	633.946	106.869	740.816	1082.1020	1329.616
10:30	758.710	111.948	870.658	1236.1965	1329.616
11:30	824.012	114.381	938.393	1316.0186	1329.616
12:30	824.012	114.381	938.393	1316.0186	1329.616
1:30	758.710	111.948	870.658	1236.1965	1329.616
2:30	633.946	106.869	740.816	1082.1020	1329.616
3:30	461.622	98.4610	560.084	864.12617	1329.616

Table:6 Calculated Solar Radiation - 28th May, 2016

Average Beam Radiation (Avg.Gcb) =(633.9469905+758.7104871+824.0120157+824.0120157+758.7104871+633.9469905+461.622953)= 699.280278 w/m^2
Average Beam Radiation(Avg.Gcb) =699.280278(w/m^2)

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Σ Input Q1 = 6548498.575 Joule
ΣOutput Q2 = 1720594.286 Joule
Efficiency, η = Output energy/ Input energy
= 0.262746379 i.e., 26.27 %

RESULTS & DISCUSSION

Date	Efficiency (η)	% EZfficiency (η)	Direction	Experiment Mode
3-Mar	0.2087	20.87	East-West	Non-Tracking
4-Mar	0.2226	22.26	East-West	Non-Tracking
6-Apr	0.2300	23.00	East-West	Non-Tracking
8-Apr	0.3451	34.51	North-South	Tracking
10-Apr	0.2877	28.77	East-West	Extended Film
8-May	0.2202	22.02	East-West	Non-Tracking
9-May	0.33420	33.42	North-South	Tracking
10-May	0.30379	30.37	East-West	Extended Film
26-May	0.20226	20.22	East-West	Non-Tracking
27-May	0.34906	34.90	North-South	Tracking
28-May	0.26274	26.27	East-West	Extended Film
13-Jun	0.25489	25.48	East-West	Non-Tracking
14-Jun	0.35793	35.79	North-South	Tracking
15-Jun	0.264681	26.46	East-West	Extended Film

Table:7 Calculated Solar Radiation - 28th May, 2016

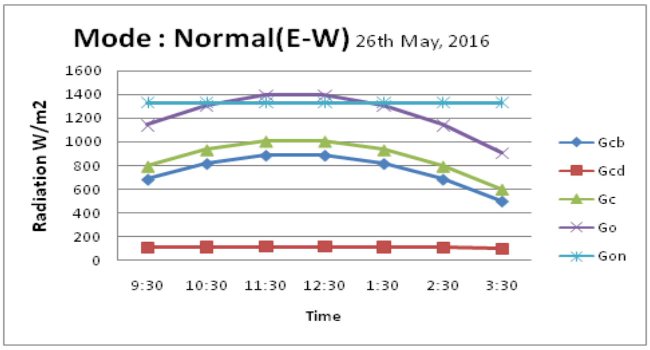

Fig.2HourlySolar Radiation Graph, 26th May 2016

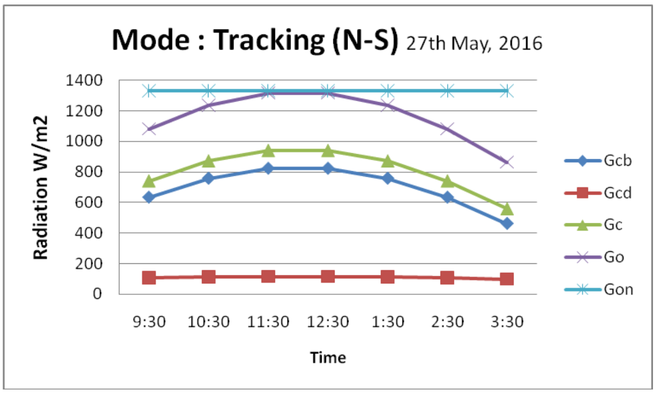

Fig.3HourlySolar Radiation Graph, 27th May 2016

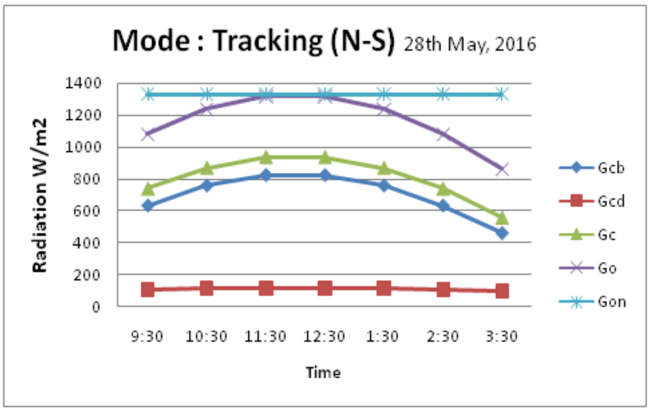

Fig.4 Hourly Solar Radiation graph, 28th May 2016

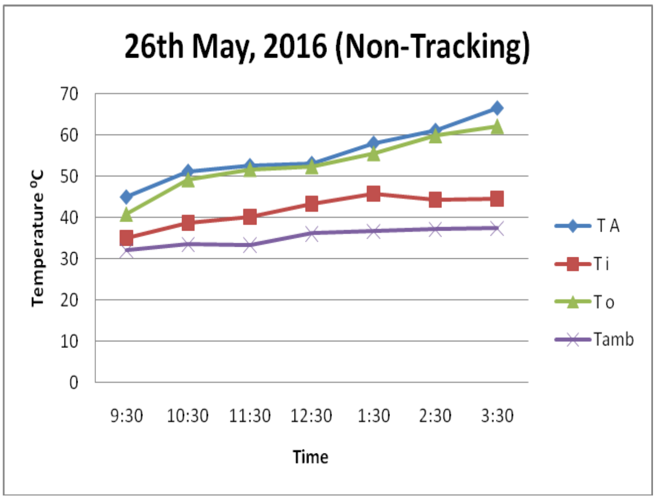

Fig.5 Temperatures Graph

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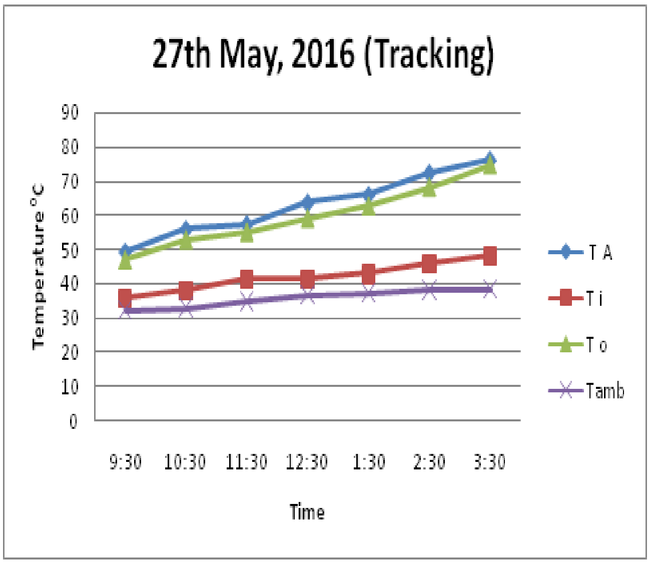

Fig.6 Temperatures Graph

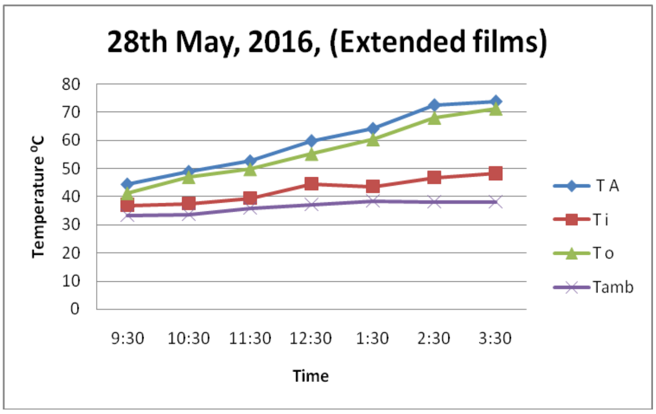

Fig.7 Temperatures Graph

From the Experimental readings, The maximum out put temperature obtained from the prototype for Non-Tracking (Mode-I) on 26th May, 2016 is 62.2°C. The maximum out put temperature obtained from the Experimental setup for Tracking (Mode-II) on 27th May, 2016 is 74.8°C.

The maximum out put temperature obtained from the prototype for Extended Film area (Mode-III) on 29th May, 2016 is 71.4°C. Ambient Temperature at the time of taking readings is between 32°C to 39°C. Hourly variation of radiation with respect to time is shown in the above graphs. Hourly Variation of total solar radiation is in the range of 792.08 W/m^2, 741.08 W/m^2 and 740.81 W/m^2 respectively.

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, 2016 to June, 2016, the following results have been observed with reference to the graph,

- The efficiency in non-tracking mode is 20.8 to 25.4 %
- The efficiency of tracking mode is 33.7 to 35.7%
- The efficiency of extended film mode is 26.4 to 30.3%

Due to the difference in climatic stipulations, the efficiency varied from time to time. Due to the shadow of extended film portion, the efficiency is getting decreased. This Experimental setup is not compatible for extended films. Out of the above three modes, tracking mode is suitable to achieve the maximum efficiency. The main research fields for this work are Material economy, Energy cost saving and pollution control.

FUTURE SCOPE

1. Optical Design and Development of Metalized polyester film Solar Concentrator for Steam production and photovoltaic for commercial and non-commercial usage.
2. 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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