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Parametric Evaluation of a Parabolic Trough Solar Collector

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Abstract

A parabolic trough collector was studied to determine its performance parameters when stationary and when tracked. The overall heat loss coefficient, heat removal factor, efficiency function, flow factor and its thermal efficiency are the factors of interest. Optimum values obtained for the collector when tracked were as follows: Collector efficiency function, 12m^{2}K/Kw; heat removal factor, 0.59, flow factor, 0.76; overall heat loss, 0.02KW/m^{2}K and thermal efficiency of 56%.

Keywords: parabolic trough, performance, parameters.

1. Introduction

Parabolic troughs have been noted for it's versatility as effective means of solar energy collection worldwide. Parabolic collectors have been found to perform variedly depending on the sizes of aperture, area, concentration ratio. Luz solar energy corporation developed a series of collectors of different sizes, namely LS-1, LS-2, LS-3 and were found to operate at different temperature ranges. Core performance parameter of parabolic collector that generates these varied temperature ranges is being investigated.

1.1 Theoretical Analysis

The targeted parametric values were computed using the following relations:

Collector thermal efficiency (η)

$$\eta = \frac{q_u}{I} \qquad - \qquad (1)$$

Collector efficiency function (F_c)

$$F_c = \eta_0 - \eta / u_L \qquad - \qquad (2)$$

The overall heat loss coefficient was calculated using the expression

$$q_u \,.\, Ac = S - U_L (T_C - T_A)\, Ac \qquad - \qquad (3)$$

Heat removal factor (FR) is given by

$$T_{Fo} = T_{Fi} + \frac{q_u (I - F_R)}{U_L F_R} \qquad - \qquad (4)$$

Collector flow factor (F^1)

$$T_2 = T_1 + \frac{q_u (I - F^1)}{U_L . F_R} \qquad - \qquad (5)$$

The above stated equations were culled from (Duffie and Beckman, 1980) and used for computation of the parameters

2. Methodology

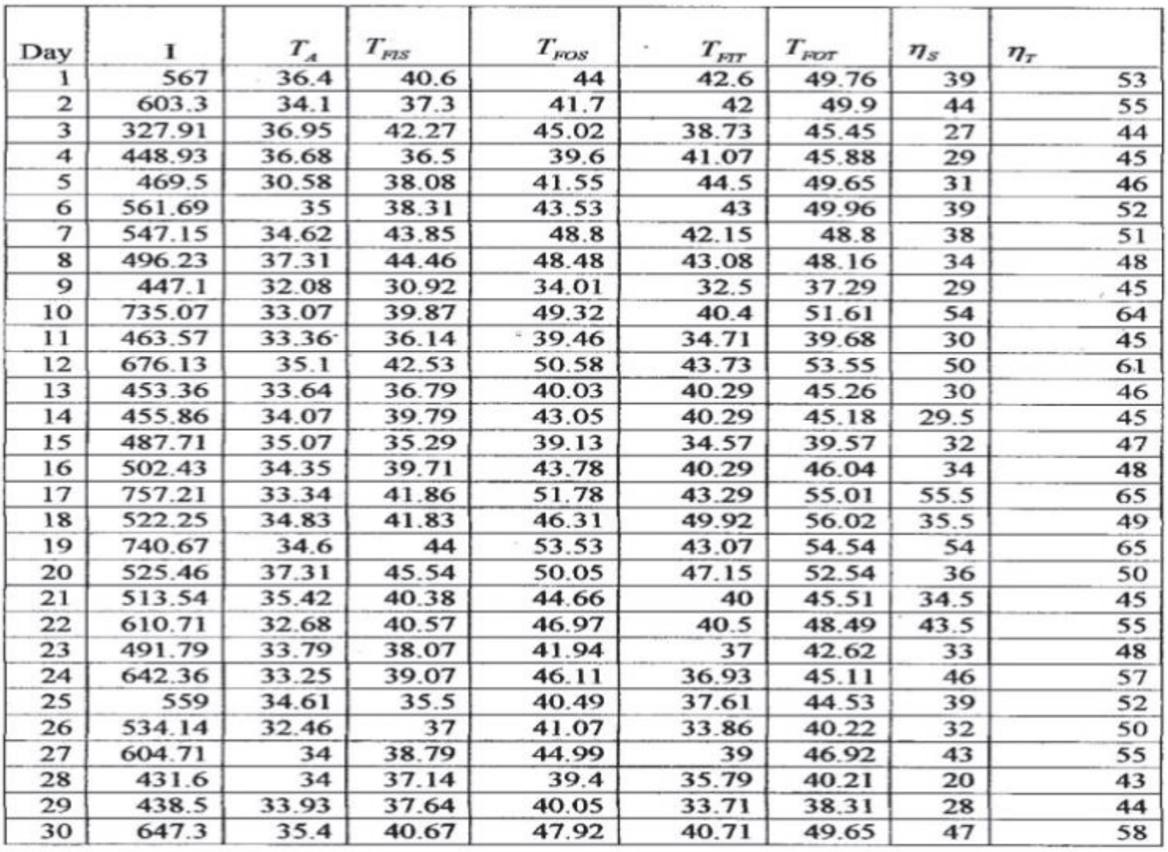
Two parabolic collectors of the size specification namely: focal length (0.32m); aperture diameter (1.10m); overall module size (1.1 x 0.4m); concentrator rim angle (82^0); concentration ratio (3.4). The reflective surface was polished stainless steel 1.0mm thickness. Suspended at the focal axis of each of the collector is an absorber made of alluminium duct of 7mm internal diameter coated with black paint. One of the collectors was mounted on a tracker while the other was stationery at the latitude of location. Digital solarimeters were used for measuring the solar radiation at Owo, in Nigeria. Digital temperatures sensors were used for reading the fluid temperatures at various instances.

Plate 1: The tracking system set-up alone

3. Results and Discussion

The two collectors of same configuration were observed experimentally for 30 days (Table 1) giving result as graphically presented for variation of fluid outlets temperatures (fig 1). The collector thermal efficiency was computed over the experimental period and shown in figure 2. Figure 3 and 4 are portraits of their thermal efficiencies and calculated efficiencies functions against temperatures above ambient respectively. Fig 5 presents the graphical comparison of their thermal efficiencies against their efficiency functions at various instances plotted from the collector performance parameters analysis in table 2.0

Table 1.0: Average daily values



Day	I	T_A	T_{FIS}	T_{FOS}	T_{FIT}	T_{FOT}	η_S	η_T
1	567	36.4	40.6	44	42.6	49.76	39	53
2	603.3	34.1	37.3	41.7	42	49.9	44	55
3	327.91	36.95	42.27	45.02	38.73	45.45	27	44
4	448.93	36.68	36.5	39.6	41.07	45.88	29	45
5	469.5	30.58	38.08	41.55	44.5	49.65	31	46
6	561.69	35	38.31	43.53	43	49.96	39	52
7	547.15	34.62	43.85	48.8	42.15	48.8	38	51
8	496.23	37.31	44.46	48.48	43.08	48.16	34	48
9	447.1	32.08	30.92	34.01	32.5	37.29	29	45
10	735.07	33.07	39.87	49.32	40.4	51.61	54	64
11	463.57	33.36	36.14	39.46	34.71	39.68	30	45
12	676.13	35.1	42.53	50.58	43.73	53.55	50	61
13	453.36	33.64	36.79	40.03	40.29	45.26	30	46
14	455.86	34.07	39.79	43.05	40.29	45.18	29.5	45
15	487.71	35.07	35.29	39.13	34.57	39.57	32	47
16	502.43	34.35	39.71	43.78	40.29	46.04	34	48
17	757.21	33.34	41.86	51.78	43.29	55.01	55.5	65
18	522.25	34.83	41.83	46.31	49.92	56.02	35.5	49
19	740.67	34.6	44	53.53	43.07	54.54	54	65
20	525.46	37.31	45.54	50.05	47.15	52.54	36	50
21	513.54	35.42	40.38	44.66	40	45.51	34.5	45
22	610.71	32.68	40.57	46.97	40.5	48.49	43.5	55
23	491.79	33.79	38.07	41.94	37	42.62	33	48
24	642.36	33.25	39.07	46.11	36.93	45.11	46	57
25	559	34.61	35.5	40.49	37.61	44.53	39	52
26	534.14	32.46	37	41.07	33.86	40.22	32	50
27	604.71	34	38.79	44.99	39	46.92	43	55
28	431.6	34	37.14	39.4	35.79	40.21	20	43
29	438.5	33.93	37.64	40.05	33.71	38.31	28	44
30	647.3	35.4	40.67	47.92	40.71	49.65	47	58

Table 2.0: collector performance parameters

η_S	Δ_{TS}	F_S	η_T	Δ_{Tt}	F_T
50	10	10	65	12	8
44	6	12	55	8	13
36	4	15	50	6	15
30	3	17	45	5	18
27	2	18	43	4	19

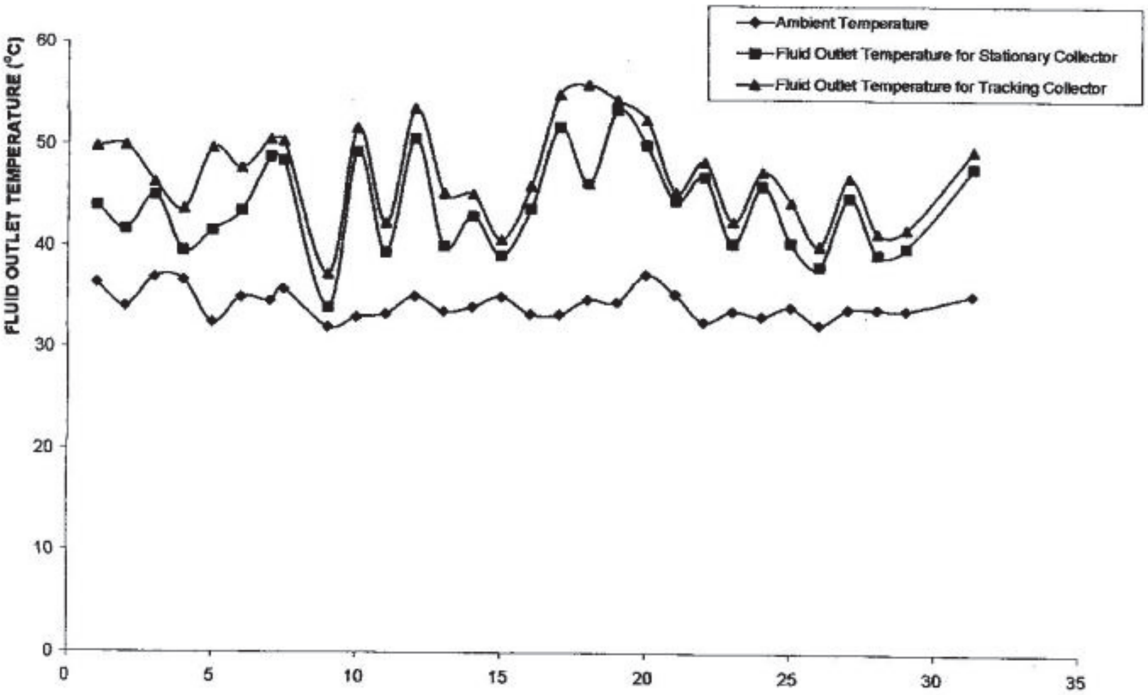


Fig 1. Fluid outlet temperature variations against the 30days experimental period

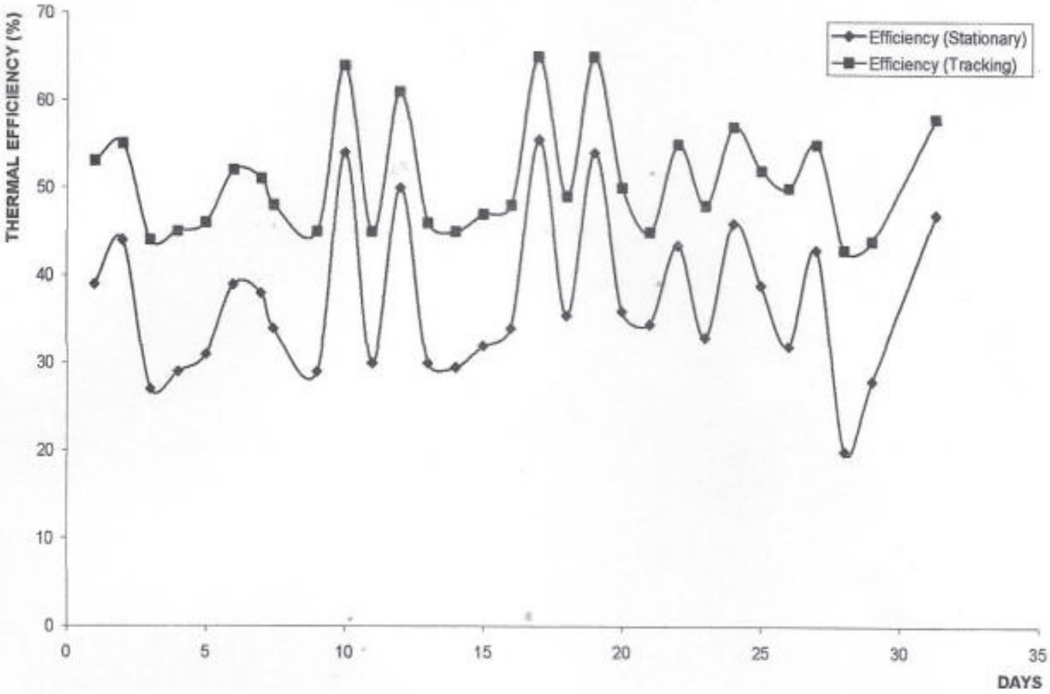


Fig 2. Collector thermal efficiency over the 30 days experimental period

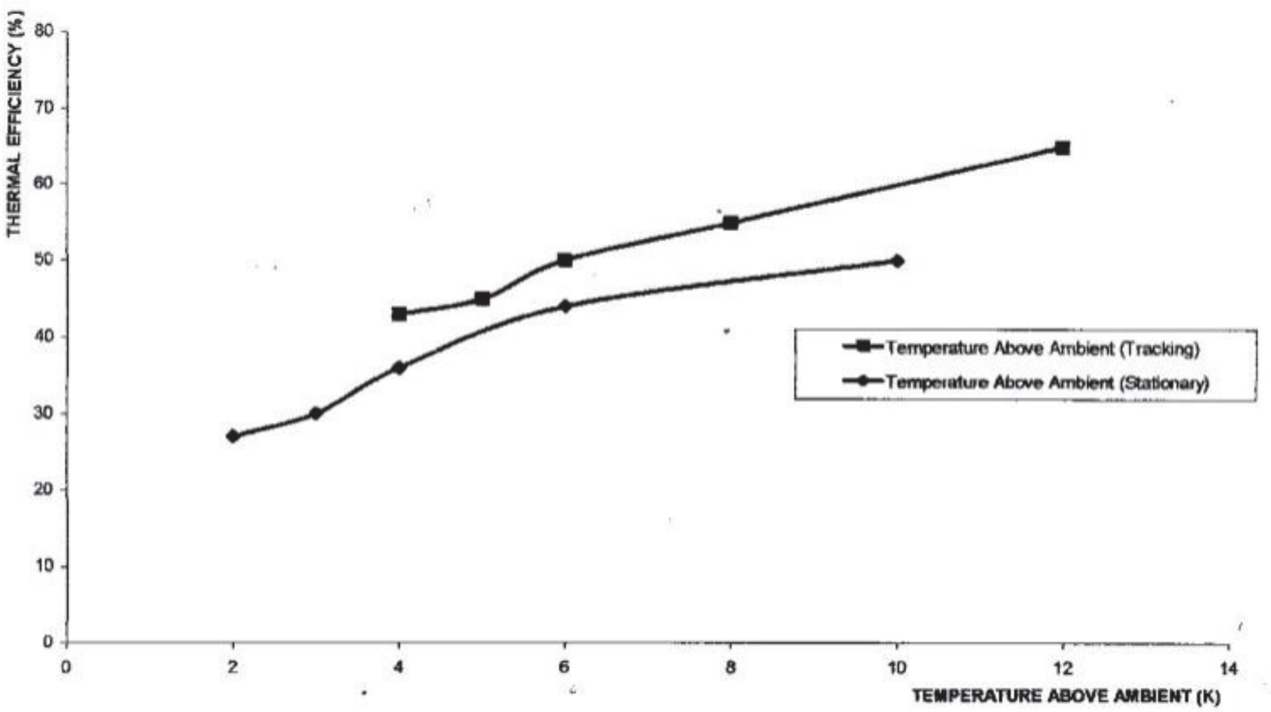


Fig. 3: Thermal efficiency against temperature above ambient

V

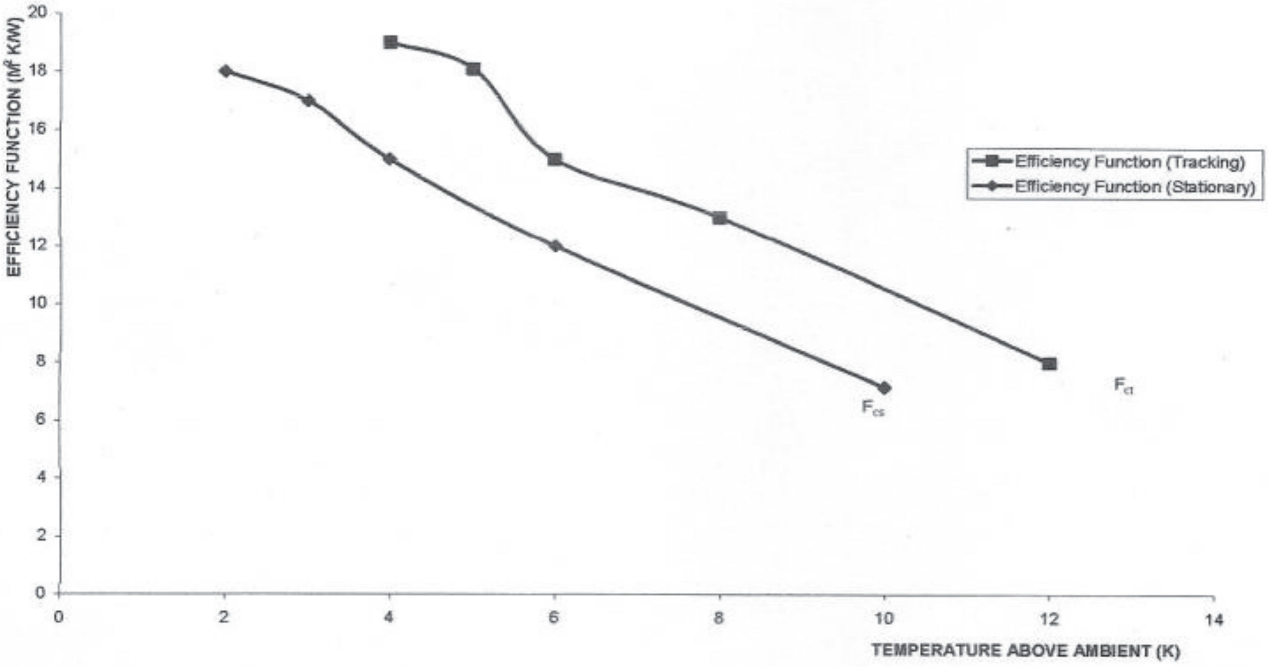


Fig. 4: Efficiency function against temperature above ambient

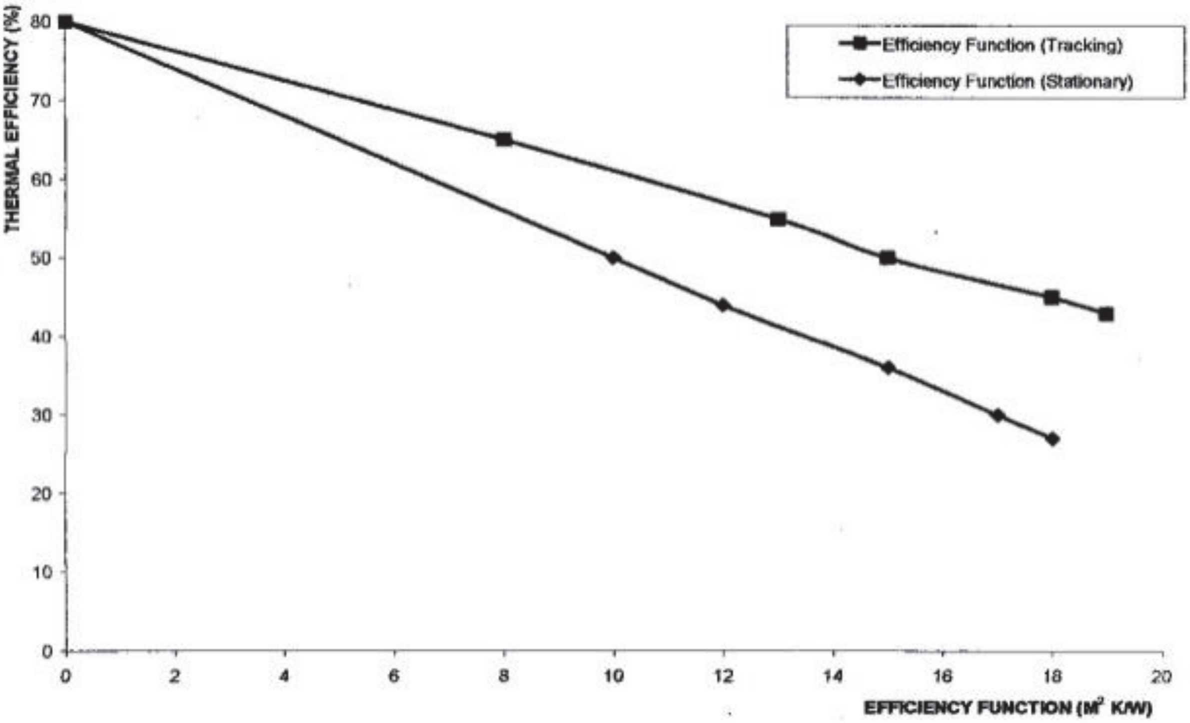


Fig. 5: Thermal efficiency against efficiency function

1. Thermal efficiency, for the stationary collector

$$\eta_S = \frac{q_{usm}}{I} \text{ x } 100\%$$

$$= \frac{0.22}{0.52} \text{ x } 100\% \quad = 43\%$$

For the tracked collector,

$$\eta_T = \frac{q_{uTm}}{I} \text{ x } 100\%$$

$$= \frac{0.24}{0.52} \text{ x } 100\% = 56\%$$

2. The collector efficiency function (F_c)

For the stationary collector

$$F_{cs} = \frac{\eta_0 - \eta_T}{U_{LS}} = \frac{0.80 - 0.43}{0.03}$$

$= 12.34m^2k/kw$

For the tracked collector,

$$F_{CT} = \frac{\eta_0 - \eta_T}{U_{LT}} = \frac{0.80 - 0.56}{0.02}$$

$= 12.00m^2k/kw$

3. Overall heat loss coefficient

The stationary collector gives the following values;
Mean ambient
temperature, $T_{AM} = 34.40^0C = 307K$
Mean collector
Temperature, $T_{CSM} = 43.00^0C = 316K$
Mean useful thermal gain,
$q_{USM} = 0.22kW/m^2$
Mean heat absorbed, $S_{UM} = 0.3/kW/m^2$
Substituting for these values in the equation (iii) below, we have
$q_{USM} . A_C = S_{SM} – U_{LS} (TC_{SM} – T_A) A_C$
where $A_C = 0.2112m^2$
that is $9U_{LS} = 0.22$
therefore, $U_{LS} = 0.03kW/m^2k$

For the tracked collector;
Mean ambient temperature, $T_{AM} = 307K$
Mean collector temperature $T_{CTM} = 319K$
Mean useful thermal gain $q_{UTM} = 0.29kw/m^2$
Mean heat absorbed, $S_{SM} = 0.44kw/m^2$
Substituting these values in the equation (iii)
$0.29 A_C = 0.44 – U_{LT} (319 – 307) A_C$
Therefore, $U_{LT} = 0.02 kw/m^2K$

4. Collector heat removal factor (F_R)

The heat removal factor was established as follows; for the stationary collector
$T_{PM} - T_{PSM} = T_{FOM} = 316k$
$T_{F1} = T_{F1SM} = 312k$
$q_{USM} = 0.22kw/m^2k$; $U_{LS} = 0.03kw/m^2k$

therefore, $3116 = 312 + \frac{0.22 (1 - F_{RS})}{0.03 F_{RS}}$

$0.22 – 0.22F_{RS} = 0.12$
Therefore, $F_{RS} = 0.46$

For the tracked, we have;
$q_{UTM} = 0.29kw/m^2$; $U_{LT} = 0.02kw/m^2k$; $T_{FTM} = 313k$

therefore, $313 + \frac{0.29 (1 -}{0.02} = 319k$

$0.12 = 0.29 – 0.29F_{RT}$
Therefore, $F_{RT} = 0.59$

5. Collector flow factor (F^1) for the stationary collector;

$$T_{FOSM} = T_{FISM} + \frac{q_U (1 – F_S)}{U_{LS}.F_{RS}}$$

$$316 = 312 = \frac{0.22 (1 – F_S)}{U_{LS}.F_{RS}}$$

$$= \frac{0.22\,(1 - F_S)}{0.03 \text{ x } 0.46}$$

Therefore, $F_S = 0.73$
Similarly for the tracked collector, we have; $T_{FOTM} = 319K$
$T_{FITM} = 313K$; $U_{UTM} = 0.29KW/m^2$; $U_{LT} = 0.02KW/m^2$ and $F_{RT} = 0.59$, Substituting these values, we have;

$$319 = 313 + \frac{0.29\,(1 - F^1{}_T)}{0.59 \text{ x } 0.02}$$

$0.29 - 0.29F^1{}_T = 0.07$
Therefore, $F^1{}_T = 0.76$

6. Collector efficiency function (F^{11})
$F^{11} = F_R/F^1$ in each case
For the stationary collector; heat removal factor, $F_{RS} = 0.46$, flow factor, $F_s{}^1 = 0.73$

$$\text{The efficiency factor, } F_S{}^{11} = \frac{F_{RS}}{F_S{}^1}$$

$$= \frac{0.46}{0.73} = 0.63$$

For tracked collector; heat removal factor,
$F_{RT} = 0.59$ and the flow factor, $F_T{}^1 = 0.76$
Therefore, the efficiency factor, $F_T{}^{11} = \dfrac{0.76}{0.59}$
$= 0.78$

Summarily, the remit of the collection performance parameters is as presented in table 4.5

4. Conclusion

The research was carried out to determine some performance parameters of a parabolic trough solar collector of aperture diameter 1.1m, focal length (0.32m) and C.R (3.4). Result show that the tracked parabolic trough is more efficient in converting solar energy to useful heat. The product of the U_L – value and collector efficiency function is a determinant of the collector thermal efficiency in each case. That the greater $U_L.F_C$ product, the less the thermal efficiency. The removal factor determines the collector temperature and is inversely proportional to it.

The heat flow function is also inversely proportional to the main fluid outlet temperature.

NOMENCLATURE

T_A = Ambient Temperature (K)
T_{AM} = Mean Ambient Temperature (K)
T_{FI} = Collector Fluid inlet temperature (K)
T_{FIM} = Mean Fluid Inlet temperature for 30 days (K)
TF_O =Collector fluid outlet temperature (K)
T_{FOM} = Mean fluid outlet temperature (K)
T_{FIM} = Mean fluid inlet temperature
T_C = Collector temperature (K)
T_{CM} = Mean collector temperature for n = 30days (K)
I = Solar insolation (Wm^{-2})
I_M = Mean solar insolation for n = 30days (Wm^{-2})
η = Transmittance
α = Absorptance
A_C = Collector surface area (m^2)

U_L =Overall heat loss coefficient ($Wm^{-2}K$)
U_{LS} = Overall heat loss coefficient for the stationary collector $Wm^{-2}K$
U_{LT} = Overall heat loss coefficient for the tracking collector ($Wm^{-2}K$)
q_U = Useful heat form (kWm^{-2})
S = Heat absorbed Wm^{-2}
q_L = Thermal loss Wm^{-2}
η = Conversion factor or optical efficiency (%)
η = Collector thermal efficiency (%)
η_{CS} = Thermal efficiency of the stationary collector (%)
η_{CT} = Thermal efficiency of the tracking collector (%)
C_P = Specific heat capacity $kJ\ kg^{-1}\ K$
T = Time (Hour)
m = Mass flow rate $kg\ s^{-1}$
M_r = Total mass of fluid transferred over a period of time (kg)

Please note that subscripts S and T are included to indicate the stationary and tracking collectors, respectively.

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