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Comparative Performance of Two Discrete Solar Collectors

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Abstract: The performance of two discrete solar heating systems have been studied. One of the collector systems was designed to track the sun while the other was to remain stationary. A 30 day performance test for both collectors was carried out on clear days and a semi-cloudy days. The study revealed that for the experimental period and under the same conditions the tracking and non-tracking collector indicated mean values of the useful heat gain of 290 and 220 W m^{-2}, overall heat loss coefficient of the collectors being 2.5 and 5.8W m^{-2}K, while the mean thermal efficiencies of the collectors were 56 and 43%, respectively.

Key words: Insolation, collectors, performance, tracking, non-tracking, useful heat

INTRODUCTION

With increasing demand and cost of energy worldwide and in many parts of the world conventional energy sources are fast depleting and becoming expensive. Solar energy collection (Adeyemo, 1997) is now receiving considerable attention for space heating, drying, heating purposes and air-conditioning. Conventional imaging solar concentrators such as parabolic trough (Heiti and Thodos, 1983) and the hemispherical power-bowl (Meinel and Meinel, 1974) have been utilised almost exclusively for establishing elevated temperatures. However, these devices require continuous diurnal tracking of the sun to produce relative performance. Tracking the system keeps the solar collector aperture pointed in the optimum direction so as to minimise the incident angle and keep the solar image centred in the absorber as the sun moves across the sky (Kreith and Kreith, 1981). The tracking system made use of gear drives and kinematic linkages for accurate focusing of the reflector. Work at the University of Chicago with non-evacuated receiving and cusp collectors demonstrated efficient performance at operating temperatures up to 150°C (Rabl *et al*., 1979). A 6.5X concentrator containing a slightly oversized steel absorber tube and aluminized mylar reflectors yielded an optical efficiency of 0.68 with overall heat loss coefficient of 1.58W m^{-2}K.

A parabolic trough of lower concentration ratio 3.0X, with an array of non-imaging collectors designed to function with a vertical fin type of absorber has been successfully providing space heating at the bread spring elementary school near Gallup, New-Mexico. Research works with compound parabolic concentrator as a secondary or booster collector has presently increased the concentration ability of a conventional focussing concentrator (Gallagher and Winstom, 1986).

In Japan an experimental system consisting of east-west one-axis tracking collectors feeding north-south axis tracking collectors were constructed for a number of different loads (Gordon and Sattiel, 1986). Certain advance concepts involve the use of a CPC to increase the energy output of photo-electrochemical cells by 20% through concentration of the insolation (Roderick, 1999).

Also recent work with a compound parabolic concentrator as a secondary or booster collector has greatly increased the concentration ability of a conventional focussing concentrator alone.

Solar tracker has been discovered to boost the capacity of a collector by 50% when used for tracking a PV pumping system (Lunde, 1980). This work studies the performance of a tracked parabolic trough collector relative to stationary type of the optical efficiency 0.8 and concentration ratio 3.4X.

Theoretical analysis: The basic approach to measuring collector performance is to expose the operating collector to solar radiation and to measure the fluid temperature and fluid flow rate (Adeyemo, 2002). The following parameters shall be computed (Duffie and Beckman, 1980) for the experimental period:

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- Hourly insolation, I obtained from measured data in W m^{-2}.
- The useful heat gain is $Q_u = mC(T_{fo}-T_{fi})$ in kJ.
- The thermal loss Q_L was computed by using the expression $Q_L = S-Q_U$.
- Efficiency, η_c of the collector can be calculated from the expression.

$$\eta_c = \frac{\text{Total useful heat gain}}{\text{Total insolation}}$$

$$\eta_c = \frac{q_U}{I} = \frac{A_c F_R\left[S - U_L(T_{FI} - T_A)\right]}{A_c I F_R}$$

- Overall heat loss coefficient U_L. The mathematical expression for the overall heat loss coefficient is:

$$Q_{US} = S - U_L\left[(T_{CM} - T_{AM})\right]A_C$$

MATERIALS AND METHODS

The tracked system and the stationary system were designed and constructed for the purpose of experimentation. The concentrator and absorber unit for the 2 systems were made of the same modules (Table 1 and 2).

The parabolic trough (Dudley and Evans, 1995) concentrator, made of a mild steel frame, with a hardboard overlay is covered with stainless steel reflector. Suspended at the focal axis of the concentrator is the absorber made of aluminium duct of 7 mm internal diameter, 1 mm thickness arranged sinusoidally into aluminium fins and coated with black paint. One of the concentrators was made to track the sun by a mechanism achieved by means of a gearbox driven by an electric motor via a V-belt (Fig. 1). Water was made to flow from a storage tank through a hose into the absorber tubing and to return to the storage tank after gaining sufficient heat. The flow of the water is by gravity feed. Figure 1 describes the experimental set-up of the 2 systems.

Table 1: Concentrator modules

Focal length	0.32 m
Aperture Diameter	1.10 m
Overall Module size	1.1×0.4 m
Concentrator weight	10.629 kg
Concentrator rim angle	82°
Concentration ratio	3.4
Reflective surface options	Polished stainless steel 1.0 m thickness

Table 2: Receiver specifications

Absorber tube outside diameter	8 mm
Absorber material	Aluminium
Selective surface optical efficiency	0.80
Absorber envelope material	Borosilicate glass
Total surface area	0.1802 m^2
Weight of absorber	2.956 kg


Fig. 1: The experimental set-up of the two systems

Readings of the solar radiation (insolation), ambient temperatures, fluid inlet and outlet temperatures were taken during the 30 days experimentation 9.00-16.00 h local time at every 30 min intervals, at Owo, Nigeria, a locality at latitude 7.1°N. Performance values were computed from mean values of measured data as shown on Table 2.

RESULTS AND DISCUSSION

The results of the experimental work on the tracking and stationary collectors have shown from the performance analysis of the collectors the effect of tracking the sun for better energy concentration compared to the stationary collector.

The average daily values of solar radiation, ambient temperature, fluid inlet and outlet temperature as recorded from experimental data for location-Owo, Nigeria, Latitude 7.1°N, have been used for the performance analysis of the collectors to obtain the useful heat, absorbed heat, efficiency etc. the mean values for the experimental period of 30 days were generated from the average from the average daily values.

The results of performance analysis carried out from the experimentation on the two collectors shows some significant comparison and have been tabulated on Table 3 and 4.

Table 3 shows the daily values of solar radiation intensity I, W m^{-2} the useful heat, qu, W m^{-2}, the absorbed heat S, W m^{-2} and the heat loss, W m^{-2} over the experimental period for both stationary and tracking collectors. The table shows the trend in variation in these parameters with some fluctuations due to cloudiness. The trend in both collectors is better visualized from the plotted graphs. Figure 2 shows a comparison of the useful heat from both the non tracking and tracking collectors, with highest values being 234 and 492 W m^{-2}, respectively. Figure 3 shows the comparison of the heat absorbed over the experimental period for both

Table 3: Collector daily thermal fluxes

Day	I, W m^{-2}	q_{US} W m^{-2}	S_S W m^{-2}	q_{LS} W m^{-2}	q_{UT} W m^{-2}	S_T W m^{-2}	q_{LT} W m^{-2}
1	567	078	318	240	301	454	160
2	603	120	338	218	332	483	151
3	428	012	239	227	188	342	154
4	449	022	251	229	202	359	157
5	470	118	263	145	216	376	160
6	562	084	314	230	292	449	157
7	547	077	307	230	279	438	159
8	496	049	278	229	238	397	159
9	447	023	251	228	201	358	157
10	736	220	412	192	471	589	118
11	464	028	260	232	209	371	162
12	676	179	379	203	412	541	129
13	453	027	254	227	209	363	155
14	456	028	256	228	205	365	160
15	488	039	273	234	229	390	161
16	502	020	211	231	241	302	161
17	757	234	424	190	492	606	114
18	522	063	292	229	256	417	161
19	741	222	415	193	481	593	112
20	525	063	294	231	263	420	157
21	514	057	288	231	231	411	180
22	611	122	342	220	336	489	153
23	492	044	276	232	236	394	158
24	642	141	360	219	366	514	148
25	559	084	313	229	291	447	156
26	534	043	299	256	267	427	160
27	605	114	342	228	333	488	155
28	432	015	258	253	186	369	183
29	439	018	246	228	193	351	158
30	647	149	363	214	375	518	143

Table 4: Measured and computed parameters

Day	I, W m^{-2}	T_A, °C	T_{FIS}, °C	T_{FOS}, °C	T_{FIT}, °C	T_{FOT}, °C	η_S, %	η_T, %
1	567.00	36.40	40.60	44.00	42.60	49.76	39.00	53.00
2	603.30	34.10	37.30	41.70	42.00	49.90	44.00	55.00
3	327.91	36.95	42.27	45.02	38.73	45.45	27.00	44.00
4	448.93	36.68	36.50	39.60	41.07	45.88	29.00	45.00
5	469.50	30.58	38.08	41.55	44.50	49.65	31.00	46.00
6	561.69	35.00	38.31	43.53	43.00	49.96	39.00	52.00
7	547.15	34.62	43.85	48.80	42.15	48.80	38.00	51.00
8	496.23	37.31	44.46	48.48	43.08	48.16	34.00	48.00
9	447.10	32.08	30.92	34.01	32.50	37.29	29.00	45.00
10	735.07	33.07	39.87	49.32	40.40	51.61	54.00	64.00
11	463.57	33.36	36.14	39.46	34.71	39.68	30.00	45.00
12	676.13	35.10	42.53	50.58	43.73	53.55	50.00	61.00
13	453.36	33.64	36.79	40.03	40.29	45.26	30.00	46.00
14	455.86	34.07	39.79	43.05	40.29	45.18	29.50	45.00
15	487.71	35.07	35.29	39.13	34.57	39.57	32.00	47.00
16	502.43	34.35	39.71	43.78	40.29	46.04	34.00	48.00
17	757.21	33.34	41.86	51.78	43.29	55.01	55.50	65.00
18	522.25	34.83	41.83	46.31	49.92	56.02	35.50	49.00
19	740.67	34.60	44.00	53.53	43.07	54.54	54.00	65.00
20	525.46	37.31	45.54	50.05	47.15	52.54	36.00	50.00
21	513.54	35.42	40.38	44.66	40.00	45.51	34.50	45.00
22	610.71	32.68	40.57	46.97	40.50	48.49	43.50	55.00
23	491.79	33.79	38.07	41.94	37.00	42.62	33.00	48.00
24	642.36	33.25	39.07	46.11	36.93	45.11	46.00	57.00
25	559.00	34.61	35.50	40.49	37.61	44.53	39.00	52.00
26	534.14	32.46	37.00	41.07	33.86	40.22	32.00	50.00
27	604.71	34.00	38.79	44.99	39.00	46.92	43.00	55.00
28	431.60	34.00	37.14	39.40	35.79	40.21	20.00	43.00
29	438.5	33.93	37.64	40.05	33.71	38.31	28.00	44.00

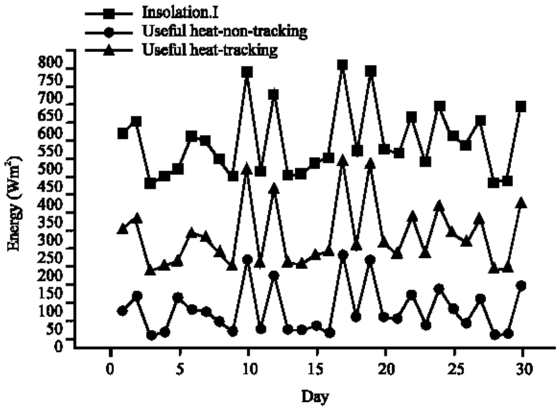

Fig. 2: Useful heat versus time -experimental period,

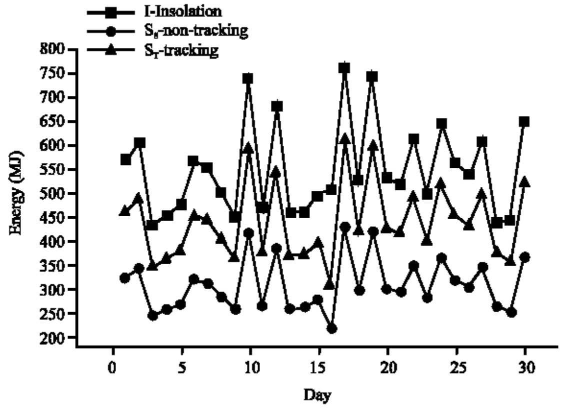

Fig. 3: Absorbed heat versus time-the experimental period, day

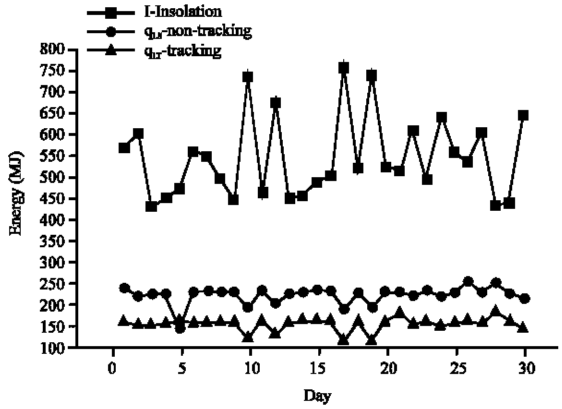

Fig. 4: Thermal losses versus time-the experimental period, days

non-tracking and tracking collectors with highest values being 424 and 589 W m^{-2}, respectively. Figure 4 follows the same trend for the thermal losses with non-tracking recording higher losses than the tracking collector with highest values being 256 and 183 W m^{-2}.

Table 4 shows the various temperature variations and efficiencies of the collector systems over the experimental period. The Table 4 shows higher fluid inlet temperatures for tracking system than the non-tracking, while the fluid outlet temperature for the tracking system is higher with a value of 56.02 and 47.15°C for non-tracking system. Following he same trend, the efficiencies of the collector systems showed a comparatively higher values for the tracking system than the non-tracking with highest values being 65 and 55%, respectively.

Further analysis with average or mean values for the experimental period showed that the mean value of absorbed radiation for tracking and non-tracking collectors were 440 and 380 W m^{-2}, respectively, while the mean useful heat gains were 290 and 220 W m^{-2}, respectively too. Average values of the collector efficiency for the experimental period were 56 and 43 % for tracking and non-racking systems, respectively.

This research reveals that a tracking concentrating collector and a stationary concentrating collector of the same receiver area concentrator weight, concentrator rim angle and ambient temperature with the solar intensity received on the the collector systems during the experimentation, the computational analysis shows the following:

- The tracking collector collects 1.32 times more useful heat than the stationary concentrating collector set at zenith.
- The thermal loss of the stationary concentrator was 1.57 times greater than the tracking concentrator.
- The overall heat loss coefficient is therefore a function of the thermal loss of the collector and directly proportional to it.

It was observed that the tracked system operates a remarkably higher temperatures than the untracked system.

CONCLUSION

The investigation was carried out to develop, construct and evaluate the tracking system for solar energy collection. The outcome of the work was that a solar tacking system can be built by using locally available materials. The use of the tracker enables accurate focusing of solar radiation on a parabolic trough collector.

It was observed that he tracked collector under the same ambient conditions, in the same geographical location and of similar specification was 1.31 times more efficient than the stationary concentrating collector. Also, the tracked system with a parabolic trough concentrator operates at higher temperature range than the stationary parabolic trough concentrator.

The tracking collector absorbs greater amount of heat than the untracked collector while the thermal losses for the latter was 1.78 times more the tracked collector. Collector parameters such as heat removal factor, flow factor and efficiency function were higher in the tacked system than in the untracked system.

The useful heat collected on each day of the experimental period depends on the available radiation, cloud, mass low rate the volume of the storage tank fluid and absorber unit.

The performance curve of the two systems follow a negative slope which is equivalent to the overall heat loss coefficient of the collectors and corresponds with the writing of Lunde (1980). Duffie and Beckman (1995) and the works of Adeyemo (2002). Collectors with lower thermal losses had been known to be more effective for solar energy collection. It is very clear from the Table 4 that the tracking system maintains higher operating temperatures and efficiency than its stationary counterpart.

This research will surely enhance the selection of appropriate collector materials for design purposes. It will facilitate the development of improved collector brands for industrial processes heating steam generation, air-conditioning, space heating, hot water, desalination and power generation. The Pattern of solar radiation intensity is also informative about Owo in Nigeria.

Considering the fact that the tracking collector system achieves 31% better performance and remarkably higher temperature than the non-tracking collector system, one would always prefer it for industrial process heating, photo-voltaic power generation and other meaningful applications without minding its production cost.

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).
T_{FO} = 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 = 30 days (K).
I = Solar insolation (W m^{-2}).

I_M = Mean solar insolation for n = 30 days ($W\ m^{-2}$).
τ = Transmittance.
α = Absorptance.
A_C = Collector surface area (m^2).
U_L = Overall Heat loss coefficient ($W\ m^{-2}K$).
U_{LS} = Overall heat loss coefficient for the stationary collector $W\ m^{-2}K$.
U_{LT} = Overall heat loss coefficient for the tracking collector ($W\ m^{-2}K$).
q_U = Useful heat form ($kW\ m^{-2}$).
S = Heat absorbed $W\ m^{-2}$.
q_L = Thermal loss $W\ m^{-2}$.
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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