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THERMAL PERFORMANCE OF A THERMOSYPHON DOMESTIC SOLAR HOT WATER HEATER IN LAGOS

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ABSTRACT

One of the most economical uses of solar energy is a thermos phonic domestic hot water heating. This is so because the installed equipment works at nearly full capacity throughout the year to satisfy a relatively constant domestic demand for hot tap water. The purpose of this work is to design a domestic solar hot water heating system to satisfy both hot water demands for a multi-family house and a long life system for the commercial market with available material in Lagos, Nigeria. A thermosyphon solar water heater with an absorber plate area of approximately 1m^2 and a tank capacity 500 was designed and constructed. The performance of the heater was studied. At the same time, solar radiation was recorded using a pyranometer. The system was then tested under the climatic condition of Lagos city. The maximum efficiency reached 70%, with mean storage tank temperature of 60^{0}C.

INTRODUCTION

In most African countries where the price of fuel is very high, there is strong encouragement to adopt solar water heaters in order to reduce conventional electricity water heating bills. For the underdeveloped countries there is need for the adoption of solar water heaters because many of these countries do not have naturally conventional fuels for electricity generation, but also due to the fact that the bulk proportion of the population of these countries are rural dwellers where the conventional electricity grids have not be extended.

The performance of a solar water heating system greatly depends on the performance of solar collectors. The design of the solar flat plate collector, which has a great effect on the operating expenses of any desired solar heater systems takes into consideration high efficiency and low costs. This is achieved as follows.

a. Choice of suitable dimensions and sizing from an economic point of view and the standard design for the type of solar collector (1, 2).

b. Use of suitable local materials, the possibility of fabrication by means of simple and local facilities of small factories and workshops.

Solar water heaters can be divided into two categories. The first category of conventional solar water heaters has collection and storage in separate units. (The thermosyphon passive solar water heater). The second category of solar water heaters has collector and storage in a single unit. The former has advantage of a greater capacity. It also has greater heat and friction losses through the connecting pipes. Flow is by gravity and is self regulating.

Nigeria has very good solar energy resources with an average monthly intensity of daily radiation of about 8.0 KWh/m^2/day and 5.5 KWh/m^2/day for Lagos. The best time to obtain good solar energy is between 9.00 am and 4.00 pm.

Figure 1 shows variation of the mean monthly global and solar radiation for Lagos.

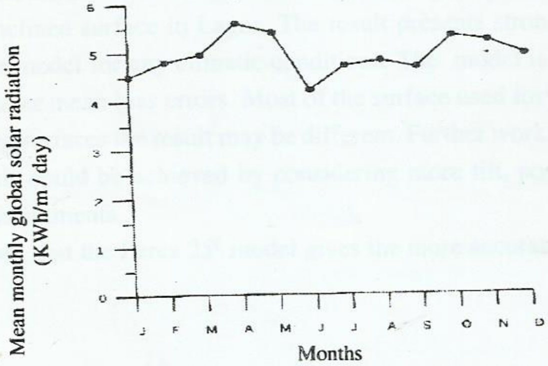

Fig. 1: Mean monthly global solar radiation for Lagos

The main purpose of the present work is to design an optimum solar water heating system to satisfy both water heating and for multi-family house and a long life span system for the commercial market with available materials in Lagos.

Description

Figure 2 shows a schematic diagram of the themoshyphonic solar water heater.

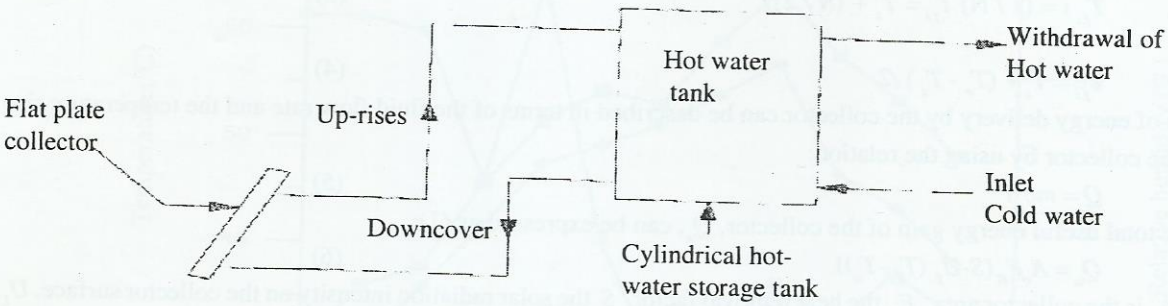

Fig. 2: Schematic diagram of Thermosymphonic solar water heater at the Lagos State University, Ojo.

The collector was mounted on a south-facing surface tilted at an angle of latitude 6^0 to the horizontal for surfaces in the Northern hemisphere facing the equator. The heat transfer fluid is water and the flow direction is from bottom to top. The inlet fluid temperature is the ambient temperature of the city.An aluminium sheet of 1.2 m * 1.0m with 1 mm thickness has been used as the absorber.

Six galvanized iron rod of inner diameter 12.5 cm diameter separated from each other by a distance of 12 cm and one metre long. The two ends of the pipes are closed by two circular galvanized iron discs having central opening of 1.25 cm for connecting them to the lower and upper header pipes. Two headers of the same rise materials with a diameter of 2.5 cm were welded to the inlet. The absorber had been isolated on the back and sides with a 5.0 cm polyuretiane foam and outlet of the risers. The surface of the pipes are coated with matt black plate. This assembly was enclosed in an aluminium casing of 0.8 mm thickness and covered with 4 mm thickness of a white glass. The flat plate collector was connected to a storage tank of 500 capacity.

The unit is installed where it will receive direct radiation from 7.00 am to 6.00 pm, at an angle of the latitude of Lagos for best performance all year round .

THEORETICAL SOLAR THERMAL PERFORMANCE OF THE SYSTEM

The sketch of the thermosyphonic solar water heater considered is shown in Fig. 2 and the full details of the mathematical model, which is based on that of Hottel and Whillier (8) is given in (9). The model is valid subject to the following assumptions:

(i) The temperature differential across the collector remains constant throughout the insolation period.

(ii) Hourly mean insolation and ambient temperature can be employed in the analysis and do not introduce significant errors in the calculated values for net hourly heat gain.

(iii) At the beginning of the insolation period, the hot water store is taken to be fully mixed at a temperature . During an hourly interval of the period of insolation the temperature rises linearly to a value . In this time period no hot water is withdrawn from the system.

(iv) The properties of water are taken to be independent of temperature.

For the no mixing situation, the water temperature in the store after n passes is (3)

$$T_n = T_s + nT \qquad (1)$$

Tn is also the inlet temperature $T_{f,i}$ for the (n+1) th pass. If the total number of passes is N then at the end of the hour we have

$$T_e = T_s + nT \qquad (2)$$

The diurnal average fluid inlet temperature at the collector is

$$T_{f,i} = (1/N)\, T_{f,i} = T_s + (N/2)T \qquad (3)$$

Hence,

$$T_{f,i} = T_s + (T_e - T_s)/2 \qquad (4)$$

The rate of energy delivery by the collector can be described in terms of the fluid flow rate and the temperature rise across the collector by using the relation:

$$Q = mc_p T \qquad (5)$$

Now the total useful energy gain of the collector, Q_u, can be expressed as (1):

$$Q_u = A_c F_R (S - U_L (T_{f,i} - T_a)) \qquad (6)$$

where A_c is the collector area, F_R the heat removal factor, S the solar radiation intensity on the collector surface, U_L is the steady state heat loss coefficient and T_a is the ambient temperature. F_R is given by

$$F_R = (Gc_p / U_L)(1 - \exp(-U_L / Gc_p \qquad (7)$$

where G, c_p and F stand for mass flow rate per collector area, specific heat at constant pressure and the collector efficiency factor respectively. U_L is given in terms of the top-loss coefficient, U_t, as

$$U_L U_t + (K/L) \qquad (8)$$

with K and L standing for thermal conductivity and length of the flow channel, respectively. The collector efficiency factor is expressed as

$$F = (1/U_L) / W (1/U_L D + U_L F (W - D) + 1/B + 1/D_i h_{f,i}) \qquad (9)$$

Here, W, D, F, B and h respectively represent the collector-pipe spacing, diameter of riser pipe, fin efficiency, pipe absorber bond conductivity and heat transfer coefficient.

The top-loss coefficient, U_t, is given by

$$U_t = N / (344/T_p - T_a) / (N + f))^{0.31} + (1/h_w) - 1 + (T_p^2 + T_a^2) / (p + 0.0425N(1-p))^{-1} + ((2N + f - 1)/g) - N \qquad (10)$$

where T_p, f and T_a represent the collector plate temperature, a factor given by , $f = 1 - 0.04h_w + 5\times10^{-4} h_w^2)(1 + 0.058N$, Stefan-Boltzmann constant and emittance, respectively.

Substituting equations (4), (6) and (7) into (5) gives

$$G = (m/A_c) = (-U_L F / c_p)\, 1/\log_e (1 - U_L T / (S - U_L (T_s + T_e)/2 + U_L T_a \qquad (11)$$

The rate of heat gained by the collector plate is

$$Q = A_c (S - U(T_p - T_a)) \qquad (12)$$

If it is assumed that all this energy is transferred to the fluid and that $U = U_L$, then Q can be eliminated between equations (6) and (12) to give

$$T_p = F_p ((1/F_R - 1)(S/U + T_a) + (T_s + T_e)/2 \qquad (13)$$

The energy balance for the whole system, over an hourly insolation period can be represented as:

$$Mc_p (T_e - T_s) = Qt - U_s A_s t ((+ (T_s + T_e)/2 - T_a) \qquad (14)$$

where M is the total mass of water in the heater and t is the time. The combination of equations (5) and (14) gives:

$$T_e = T_s (Mc_p - U_s A_s t/2) + t(mTc_p + T_a U_s A_s) / (Mc_p + U_s A_s t/2) \qquad (15)$$

Consideration of the collector useful energy gain against the heat received due to the solar insolation will provide the efficiency of heat collection as

$$C = F_R (S - U_L (T_s - T_a)) / S \qquad (16)$$

RESULTS AND DISCUSSION

Evaluation of the performance of the solar water heater system was done by recording the temperatures, water flow rate and intensity of radiation every hour. The measurements were carried out for different weather conditions. Figs. (3) and (4) show the absorber plate mean temperature distribution along the absorber (T_3) and the inlet and outlet water temperature distributions of the collector during the cloudy, bright days (T_1, T_2) with ambient temperature (T_4).

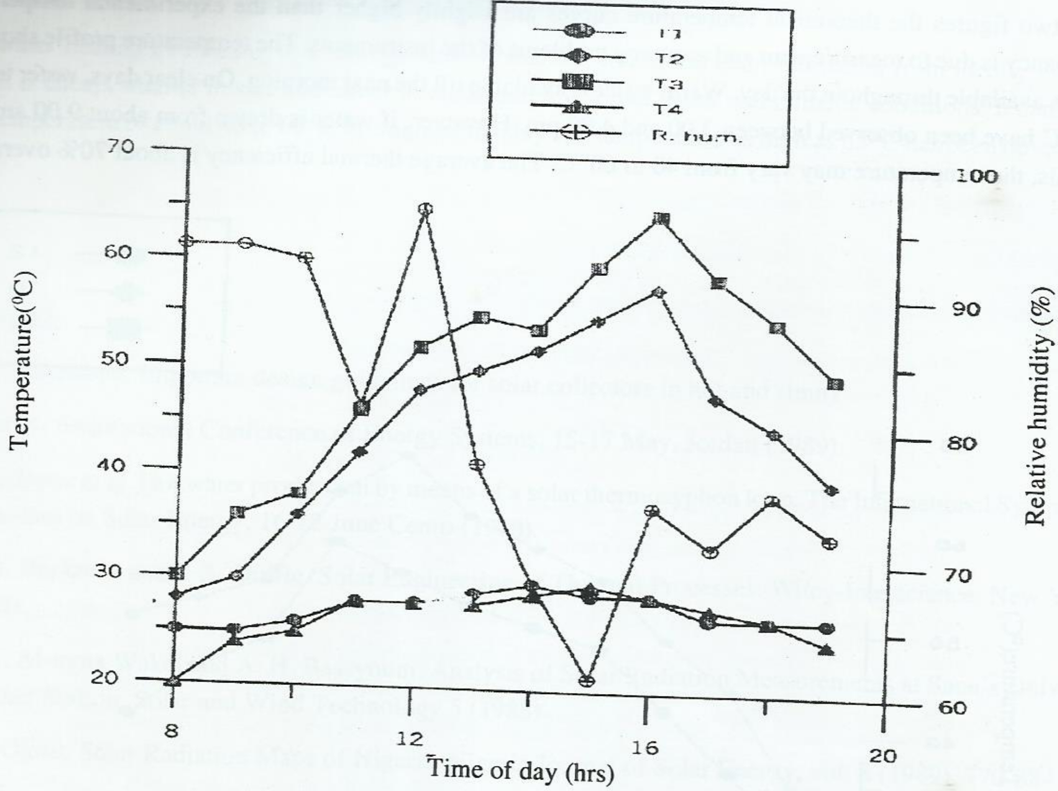

Fig. 3: Variation of absorber plate, inlet and outlet temperature for 30th August, 1995 (Cloudy day)

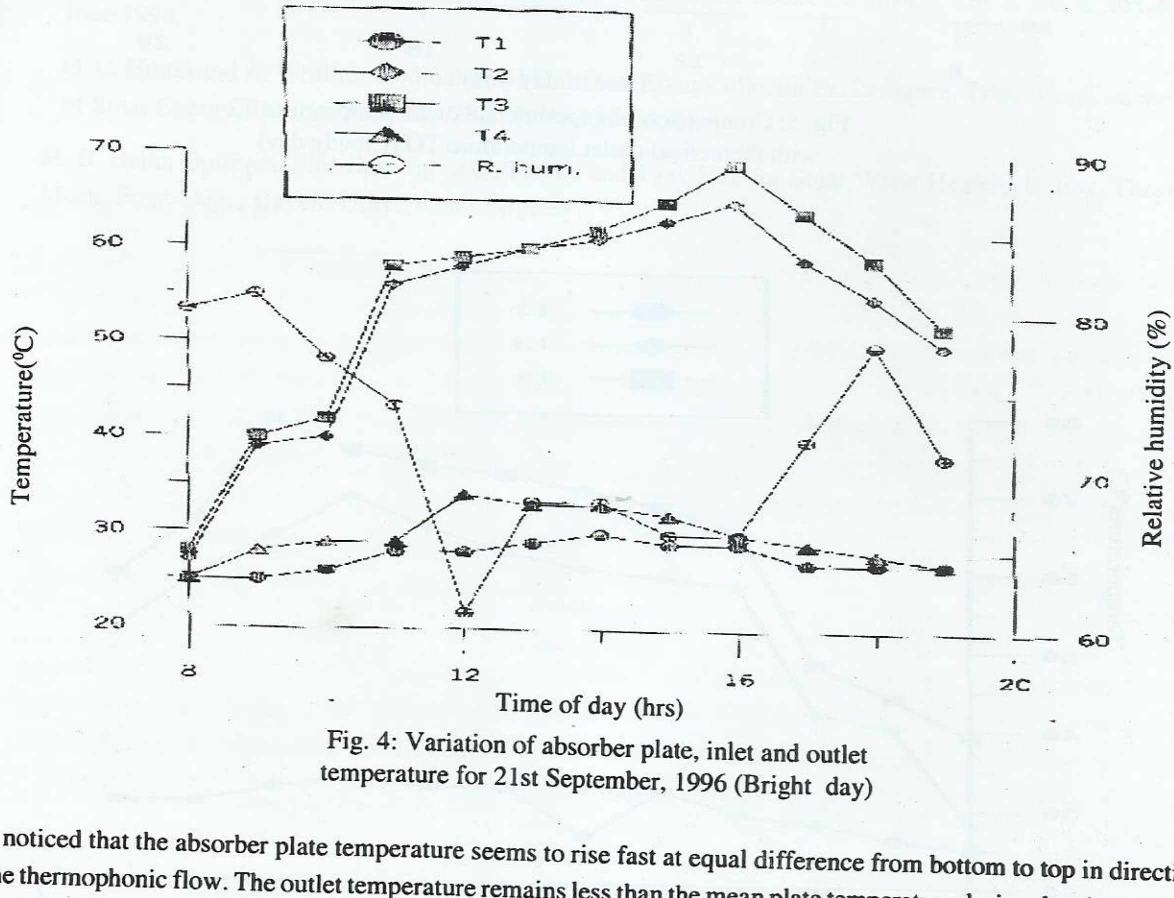

Fig. 4: Variation of absorber plate, inlet and outlet temperature for 21st September, 1996 (Bright day)

It is noticed that the absorber plate temperature seems to rise fast at equal difference from bottom to top in direction of the thermophonic flow. The outlet temperature remains less than the mean plate temperature during the observation. This is due to heat loss between the absorber plate and the inside surface of the rises.

Figs. (5) and (6) show the comparison between the theoretical and experimental results of the outlet collector temperature and mean absorber plate temperature.

In the two figures the theoretical temperature curves are slightly higher than the experimental temperature. The discrepancy is due to measurement and accuracy problems of the instruments. The temperature profile shows that hot water is available throughout the day. Warm water is available till the next morning. On clear days, water temperature of 65 °C have been observed between 3.00 and 4.00 pm. However, if water is drawn from about 9.00 am at regular intervals, the temperature may vary from 40 to 60 °C. The average thermal efficiency is about 70% overall.

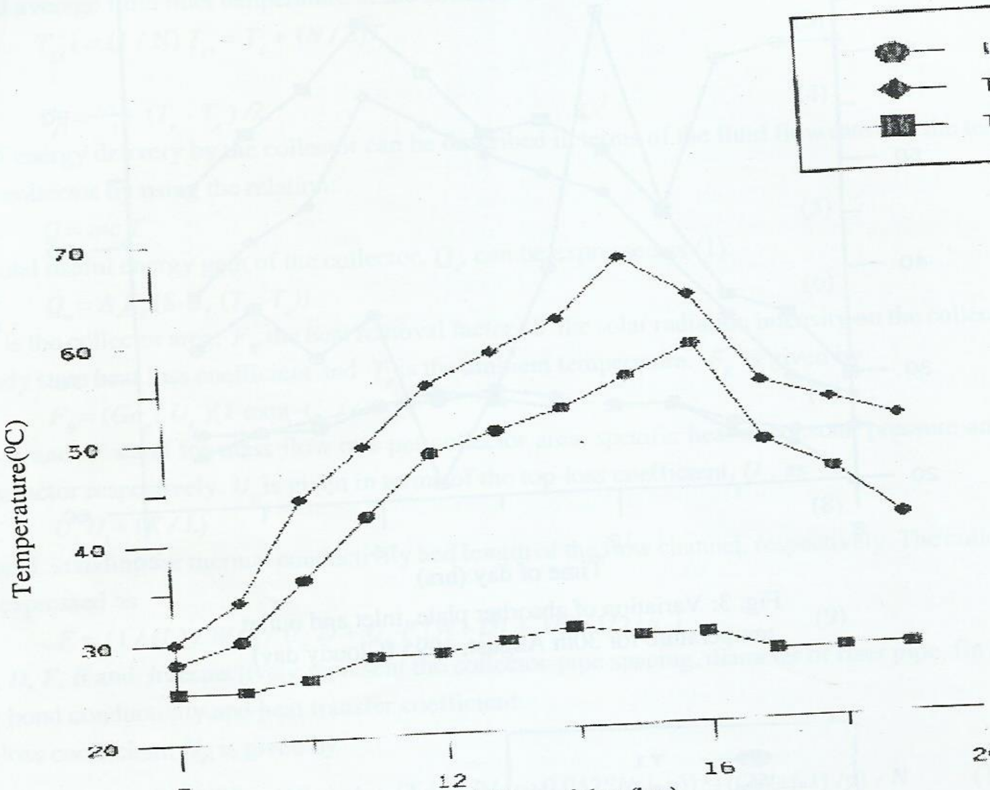

Fig. 5: Comparison of experimental outlet temperature T2 with theoretical outlet temperature TO (Cloudy day)

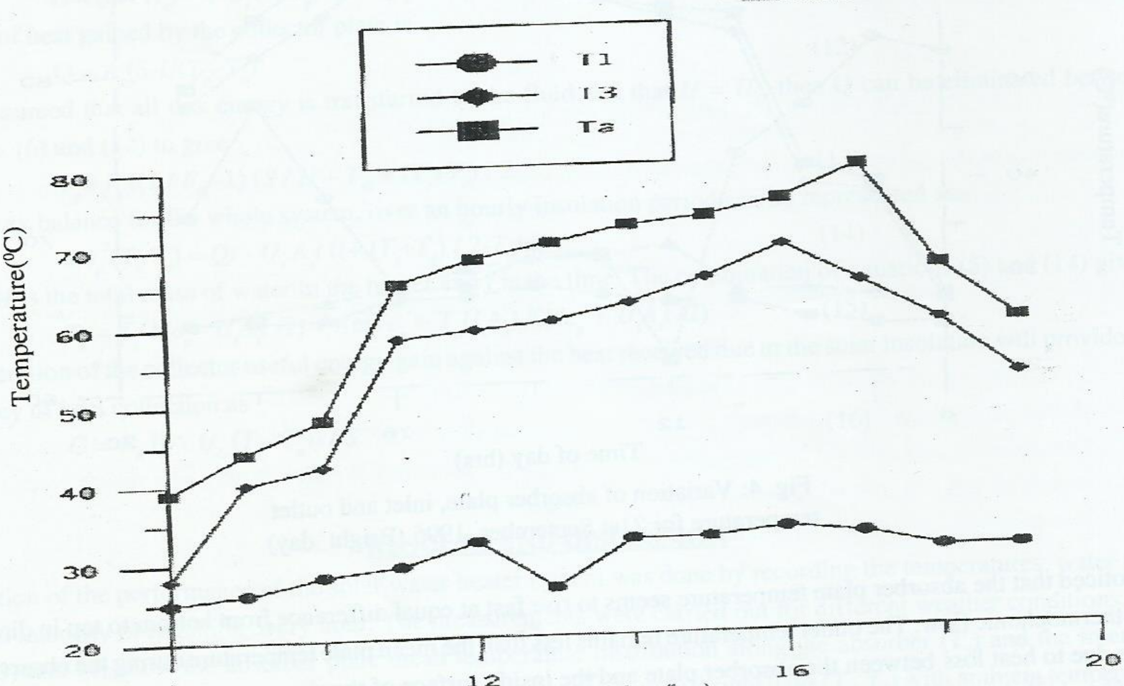

Fig. 6: Comparison of mean absorber plate temperature T3 with theoretical temperature Ta

CONCLUSION

The solar water heating circulating to a storage tank by thermosyphon has been fabricated from locally available materials. It is cheap, smaller in size and easier to construct. It is tested under real climatic conditions. It can supply water at a temperature of about 40 to 60 °C throughout the day and temperature as high as 65 °C has been observed on a clear day.

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