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Thermo Siphon Solar Water Heater

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ABSTRACT

A solar water heater using a thermo-siphon principle has been developed. Major components of the heater include: (i) a cold water tank, (ii) hot water storage tank, (iii) solar collector, and (iv) the circulation system. The tanks were made with gauge 16 galvanized steel. The hot water storage tank is insulated with 50mm thick fibre glass. The solar collector has a surface area of 1.6m^2, mounted on a frame tilted to an angle of 7 degrees. Circulation pipes are lagged with tyro foam and synthetic leather. Performance test showed that the heater recorded a maximum temperature of 72^{0}C at an average heat gain of 24 W per hour.

Keywords: *Water Heater; Thermo siphon; Insulation; Solar; Heat Gain.*

1. INTRODUCTION

Water heating primarily involves a heat gain from an energy source by the water. Traditional heat sources include biomass; fossil fuels, etc. with associated health hazards. Solar energy is fast becoming a welcome alternative source and hazard free heat source; especially in the tropics. It has a further advantage of availability and positive health implications.

Solar collectors constitute major component of solar devices. They absorb and transform solar radiations to usable form. There are two basic types, namely (Meinel, 1976):

(i) concentrating, and
(ii) non-concentrating solar collectors

Concentrating solar collectors operate on the principle that heat loss can be reduced by using a small area (a receiver) that acts as a black body. Receiver temperature can be increased by focusing the solar radiation by use of a *reflector*. The reflector-receiver arrangement is called a solar concentrator. Non-reflecting collectors are simply called flat-plate collectors. They do not have reflector units. Differences between the two basic types of collectors include:

i. Concentrating collectors absorb direct solar radiations while the flat-plate type absorbs both direct and diffused radiations.

ii. Concentrating collectors need a continuous tracking mechanism and a more expensive (pivoting) mounting.

iii. Reflecting surfaces require frequent cleaning.

iv. Solar energy absorbed per unit area is the same whether a concentrating or flat plate collector is used. Generally, concentrating collectors do not absorb more energy than flat-plate collectors, but can attain higher temperatures (Eggers-Lura, 1979).

2. DESIGN CONCEPT

Figures 1.0 and 2.0 show the schematic diagram and assembly view of the thermo siphon solar water heater respectively.

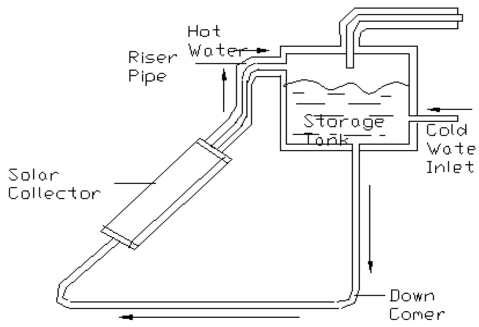

Fig. 1.0 Schematic Diagram of Thermosiphon Solar Water Heater

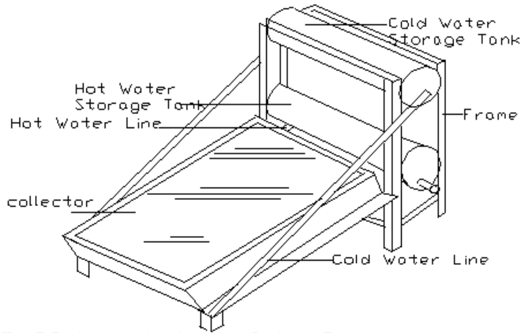

Fig.2.0 Assembly View of the Thermosiphon Solar Water Heater

3. OPERATIONAL PRINCIPLE

Water is caused by gravity to flow from the cold water reservoir to the solar collector where it absorbs solar radiations in form of heat energy. This results in density differential (natural convection) which causes the heated water to flow through the risers to the hot water tank via a common header. Thermo siphon systems generally have low flow rates through the collector, as the fluid undergoes a higher temperature rise. This accounts for low efficiency of thermo siphon systems.

4. DESIGN ANALYSIS

4.1 Assumptions

- Volume of water to be heated, v = $0.06m^3$
- Average heating time, t = 7 hours
- Average insolation, G = 430 W/m^2
- Ambient temperature, $T_a = 26^oC$
- Water inlet temperature, $T_1 = 26^oC$
- Transmittance of the cover material, ☺ = 0.9
- Absorptivity of the absorber plate (coated with black enamel paint), ✂ = 0.7
- Angle of inclination of solar collector = 7 degrees

4.2 Measured Parameters

- Thermal conductivity of risers, k_r = 385 W/mK
- Thermal conductivity of absorber plate, k_a = 225 W/mK
- Thermal conductivity of insulating material, k_m = 0.04 W/mK
- Number of cover material (glazing), n = 1

4.3 Cold Water Tank

Volume of water + Air space = 60 litres + 60 x 0.5 = 90 litres; let v = 100 litres = $0.1m^3$

For a cylindrical shaped tank; v = ✍r^2l; where l s the length of the tank; r is the radius.

Let l = 1m; r = (v/✍l) $^{1/2}$ = (0.1 /✍x 1.0) $^{1/2}$ = 0.179m; Diameter = 0.36m

4.4 Hot Water Tank

This is a double walled tank with insulation material in-between.

Let l = 1m; Diameter of inner tank = 0.276m

4.5 Insulation Thickness

Using Fourier's law of heat conduction, insulation thickness of the hot water tank is calculated as follows (Rajput, 2002):

For cylindrical vessels, heat loss per unit time, Q_l = 2✍l $(t_f – t_a)$ / [ln (r_2 /r_1)/k + 1/ $h_0 r_2$]

where t_f and t_a are final and ambient temperatures of the water and r_2 and r_1 are radii of outer and inner tanks respectively; h_0 is the convective heat transfer coefficient of outer tank; k is the thermal conductivity of insulating material.

Heat gain by water, $Q = mc_p(t_f – t_i)$

Where m is mass of water; t_i s initial temperature of water; and c_p is the specific heat capacity of water at constant pressure.

But Heat Loss by tank = Heat Gain by water; 2✍l $(t_f – t_a)$ / [ln (r_2 /r_1)/k + 1/ $h_0 r_2$] = $mc_p (t_f – t_i)$

Substituting values; $h_o = 0.96 W/m^2K$

Critical radius of insulation, $r_c = k /h_o = r_2$ (Rajput, 2002)

r_c= 0.04 / 0.96 = 0.042m ; thus, chosen thickness of insulation = 70mm

4.6 The Solar Collector

Required to design a system that will raise the temperature of 60 litres of water from an ambient temperature of 26^oC to 70^oC within a working day of the collector.

Energy gained by water, Q = 👎$_w$ v c_p Δt (Incropera, 1996)

where 👎$_w$, v, c_p , Δt are density of water, $1000kg/m^3$; volume of water; specific heat capacity of water, 4.19kJ/kgK; and temperature rise of water, respectively

Energy absorbed by collector in time, t;. Q =
$_c$ GA_p t

where

$_c$ is the collector efficiency; G is solar insolation; and A_p is area of collector plate.

Thus, 👎$_w$ v c_p Δt =
$_c$ GA_p t ; A_p = 👎$_w$ v c_p Δt /
$_c$ G t

Average value of solar insolation in Eastern part of Nigeria is $430W/m^3$ (Data from National Centre for Energy Research ad Development, UNN). Considering a collector efficiency of 40% and a daily heating period of 7 hours;

$A_p = [1000 \times 60 \times 10^{-3} \times 4190 \times (70 - 26)] / [0.4 \times 430 \times 7 \times 3600] = 1.6\ m^2$

Let collector width = 1m; then length of collector = 1.6 / 1.0 = 1.6m

Overall Heat Transfer Coefficient, $U_o = Q_l / (T_p - T_a) = (0.4 \times 430) / (100 - 26) = 2.33 W/m^{2o}C$.

Figure 3.0 shows a sectional view of the flat-plate solar collector, and figure 4.0 shows the chosen dimensions of the collector.

4.7 Materials of Construction

Aluminum was used for the solar collector since it is comparatively cheaper and has a high thermal conductivity. It is lighter and a good material for the solar absorber. It is coated with black enamel paint for higher performance. Black paint has the ability to absorb light of virtually all wavelengths (Daniels, 1977). Copper tubes were used for the risers since aluminum tubes are not sufficiently resistant to corrosion. White glass was used for the cover plate for its stability and high transmittance to visible light. It also has low transmittance to infra-red radiations.

Fibre glass was used for insulation. It is comparatively cheaper and readily available. It is widely used for its low thermal conductivity.

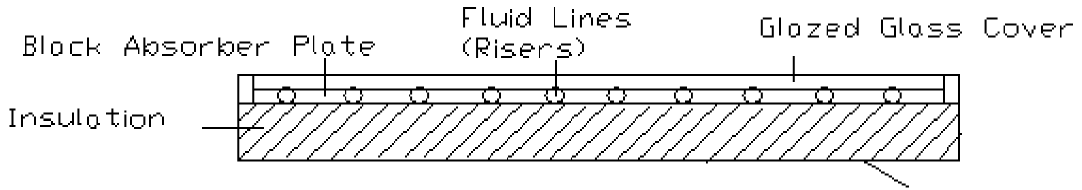

Fig.3.0 Sectional View of the Flat-Plate Collector

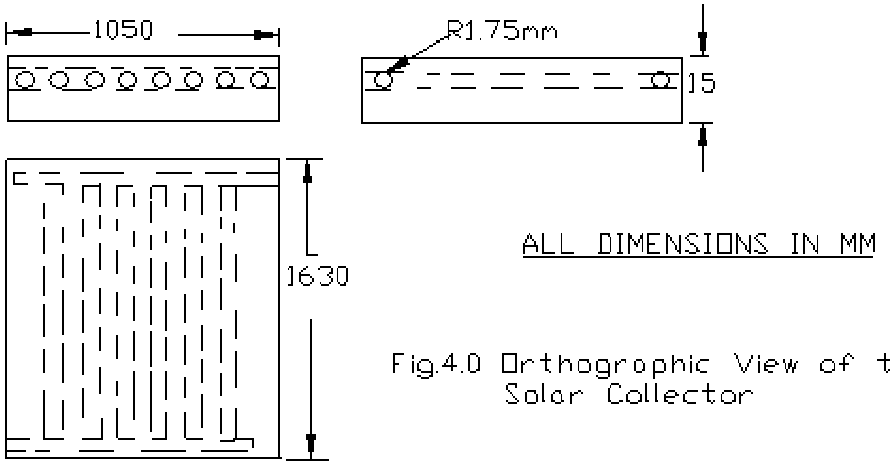

Fig.4.0 Orthographic View of the Solar Collector

5. PERFORMANCE EVALUATION

Measured Quantities Include

T_p = Temperature of absorber plate, 100°C
T_1 = Water inlet temperature, °C
T_a = Ambient temperature, °C
T_2 = Water outlet temperature, °C
G = Insolation, 430 W/m^2

Estimated quantities are

Temperature rise of water, $\Delta T = T_2 - T_1$
Heat gain by water, $Q_u = MC_p\, \Delta T$
Efficiency of the collector, **(¿)** $= 100 \times (T_2 - T_1) / T_p$

Table 1.0 shows the result of the performance test.

Table 1.0 Result of the Evaluation Test

Time	Day One °C		Day Two °C		Day Three °C		(¿)
	T_1	T_2	T_1	T_2	T_1	T_2	
10.30AM	26		26		26		
11.30AM	26	61.0	26	60.1	26	62.0	35.0
12.30AM	26	64.0	26	62.2	26	63.2	37.1
13.30AM	26	66.0	26	64.6	26	62.8	38.5
14.30AM	26	68.0	26	65.1	26	71.2	42.4
15.30AM	26	58.3	26	54.8	26	57.4	30.8
16.30AM	26	56.8	26	53.6	26	56.0	29.5
17.30AM	26	48.3	26	49.4	26	51.1	23.6

5.1 DISCUSSION

Maximum recorded efficiency = 42.4%

Maximum outlet temperature = 71.2°C

Since hot water is harvested by thermo siphon principle (through evaporation and condensation), ideal final temperature of hot water should be 100°C in the absence of any heat loss. Thus, further increase on insulation thickness is likely to improve on the water outlet temperature. Plate 1 shows a picture of the thermo siphon solar water heater.

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PLATE 1: THE THERMOSIPHON SOLAR WATER HEATER