Online ISSN: 1920-3853

Vol. 6, No. 1, Feb 2012

Print ISSN : 1715-9997

Canadian Journal of pure & applied sciences

an International Journal

SENRA

Academic Publishers

Burnaby, British Columbia

EDITOR
MZ Khan, SENRA Academic Publishers
Burnaby, British Columbia, Canada

ASSOCIATE EDITORS
Errol Hassan, University of Queensland
Gatton, Australia

Paul CH Li, Simon Fraser University
Burnaby, British Columbia, Canada

EDITORIAL STAFF
Jasen Nelson
Walter Leung
Sara Ali
Hao-Feng (howie) Lai
Ben Shieh
Alvin Louie

MANAGING DIRECTOR
Mak, SENRA Academic Publishers
Burnaby, British Columbia, Canada

The Canadian Journal of Pure and Applied Sciences (CJPAS-ISSN 1715-9997) is a peer reviewed multi-disciplinary specialist journal aimed at promoting research worldwide in Agricultural Sciences, Biological Sciences, Chemical Sciences, Computer and Mathematical Sciences, Engineering, Environmental Sciences, Medicine and Physics (all subjects).

Every effort is made by the editors, board of editorial advisors and publishers to see that no inaccurate or misleading data, opinions, or statements appear in this journal, they wish to make clear that data and opinions appearing in the articles are the sole responsibility of the contributor concerned. The CJPAS accept no responsibility for the misleading data, opinion or statements.

CJPAS is Abstracted/Indexed in:
EBSCO, Ulrich's Periodicals Directory, Scirus, CiteSeerX, Index Copernicus, Directory of Open Access Journals, Google Scholar, CABI, Chemical Abstracts, Zoological Records, Biblioteca Central, The Intute Consortium, WorldCat. CJPAS has received Index Copernicus Journals Evaluation for 2010 = 4.98

Editorial Office
E-mail: editor@cjpas.ca
: editor@cjpas.net

SENRA Academic Publishers
7845 15th Street Burnaby
British Columbia V3N 3A3 Canada
www.cjpas.net
E-mail: senra@cjpas.ca

Print ISSN 1715-9997
Online ISSN 1920-3853

Volume 6, Number 1
Feb 2012

CANADIAN JOURNAL OF PURE AND APPLIED SCIENCES

Board of Editorial Advisors

SENRA Academic Publishers, Burnaby, British Columbia
Vol. 6, No. 1, pp. 1855-1862, Feb 2012
Online ISSN: 1920-3853; Print ISSN: 1715-9997

Canadian Journal of pure&applied sciences

EVALUATION OF THE TEMPERATURE EFFECT OF A THERMOSYPHON SOLAR WATER HEATER

*Aasa, SA and Ajayi, O O
Department of Mechanical Engineering, Covenant University
P.M.B 1023 Ota, Ogun state, Nigeria

ABSTRACT

This study investigated the effect of system temperature on the performance of thermosyphon solar water heater. Solar collector was designed and developed with galvanized steel, wood and copper pipes for the experiment. While the copper pipes serves as the tube through which the cold water flows, the wood was employed for the frame and stand, and the galvanized steel for the collector material. Also employed were two hot and cold water tanks of 60 and 110 litre capacities respectively. The period of experiment were taken to be 3 days each for sunshine, sun-off and moderate sunshine days, with the average data employed for the analysis. The results showed that temperature has a domineering effect on the performance of the thermosyphon system. The maximum outlet temperature obtained for sunshine, moderate sunshine and sun-off days were 94.6, 73.5 and 51^{o}C respectively. Also the system efficiency was found to be 61.04%, demonstrating good performance. However, considering the fact that the experiment was carried out in rainy season (between April and September), it was concluded that if it is repeated during the dry periods (October to March), the efficiency of performance will be more as these period is characterized by low cloud cover, high temperature and high radiation intensities. The outcome of the study was compared with published results and it clearly demonstrates that the designed system can suitably be employed for both domestic and industrial uses.

Keywords: Thermosyphon, solar water heater, flat plate collector, system temperatures.

INTRODUCTION

Globally, water heating dominates energy needs of household, and in developing countries it is the most intensive and therefore the most expensive (Beckman and Duffie, 1991). The intensity of energy demand in developing countries has been identified as one of the principal contributors to deforestation (Rasheed, 1995). These energy options are however unsustainable, costly, depleting and contributes to build-up of green house gases in the atmosphere. With the rural communities faced with limited fuel and intermittent electricity supplies, ability to access hot water for hygiene and domestics uses become restricted. More so, in terms of energy consumptions water heating is second only to space heating and air conditioning in most developed nations. Making it very important to find alternative ways by which the process can be achieved without necessarily burdening the environment. Such process must however be affordable to rural communities. The sources of the energy must be easily accessible, naturally applicable, enormously available, non toxic and providing valuable and usable energy (Agbo and Oparaku, 2006).

One potential option is the use of solar water heating technology. This technology is employed in many parts of the world for a wide range of used patterns and climatic conditions. Today engineer and scientist can harness solar energy with common materials and basic technology. Globally, the application of solar water heating began early twentieth century. Thermosyphon solar water heater is the oldest type of water heating system and has been in used since 1920 in Israel and United State of America. With availability of resources, it is pertinent that sustainable alternatives are highly imperative and its prospect is bright (Agbo *et al*., 2005).

Thermosyphon solar water heater is a passive system in which the flow of working fluid occurs by natural circulations. As the working fluid in the collector is heated up, its density changes and becomes less dense, rising up naturally to the header pipe through the riser tubes. This is an advantage as hot water could be made available all year round. The complete design of Thermosyphon solar water heater involves system design, optimization and integration with the existing heating system. Detail design involves accurate information about ambient condition, which is a complex process (Agbo, 2006). Moreover, various studies have been carried out on thermosyphon system's performance. Some of these studies include a proposed modified efficiency for thermosyphon solar heating systems achieved by modifications of CNS 12557 B7276 test standard. It employed a precise, on-line operation to derive the heat

*Corresponding author email: samson.aasa@covenantuniversity.edu.ng

removal efficiency of the system (Chang *et al*., 2004). Another involved the performance of a closed coupled thermosyphon system which employed a vertical baffle and cross plumbing to divide the water tank into two sections (Morrison, 1986). More on this was the evaluation of the effect of hot water withdrawal rate which was based on gross analysis of simulated hot water temperature (Agbo, 2006). Some other studies involved the performance estimation of a thermosyphon water heater, to assess the level of its prospect under various weather conditions (Agbo and Unachukwu, 2006). Also, a study which dwelt on the performance evaluation of solar operated thermosyphon hot water system was analysed based on its numerical and experimental results (Adegoke and Bolaji, 2000). All of these studies have basically dwelt on estimating the system's performance which was to evaluate the values of density, pressure or temperature. The deductions of effectiveness were then based on the relative values of these parameters. However, none of the studies have been able to determine and explain the actual individual effects of the parameters on the system's performance. It is worthy of note also, that of the three parameters, temperature is the most important and the domineering parameter. The knowledge of the value and effect of temperature on the system can lead to the evaluation of the values of density and pressure and by extension their effects. This study is therefore used to focus on determining the exact effect of system temperature on the performance of a thermosyphon water heater using the average experimental data obtained and also evaluate the magnitude of the pressure and density and their effects using the establish expression derive from this study with further formulation of correlation relationship between temperature, density and pressure of the system.

MATERIALS AND METHODS

In order to carry out the study, the thermosyphon solar water heater was first designed and constructed. The materials employed for the construction were mild steel, galvanized steel and wood. The mild steel was employed for the construction of the outer part of the hot water tank and the support stand of the cold water tank. Also, galvanized steel was used for the construction of the inner part of the hot water tank, cold water tank and the flat plate collector. The inner part of the hot water tank was lagged with fibre glass. The solar collector was supported with the aid of a wooden stand. Figure 1 presents the engineering drawing of the thermosyphon system while figure 2 presents the exploded view of the solar collector.

The system design was carried out based on already established principle for thermosyphon system (Fairbairn and Mario, 1999).

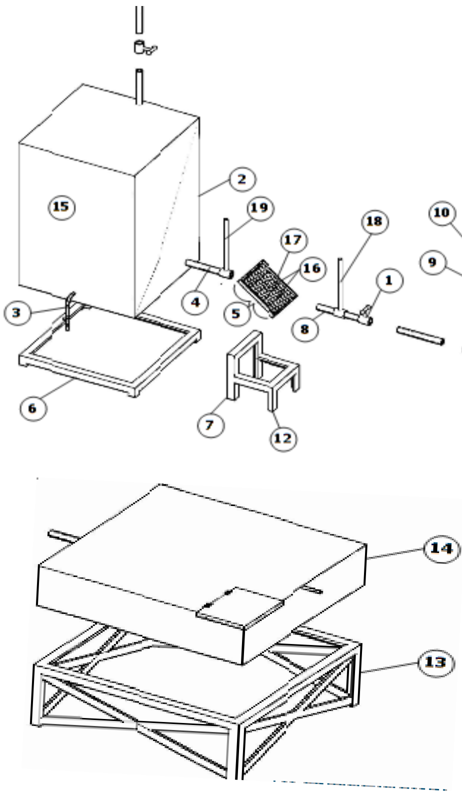

Fig. 1. Thermosyphon Solar Water Heater.

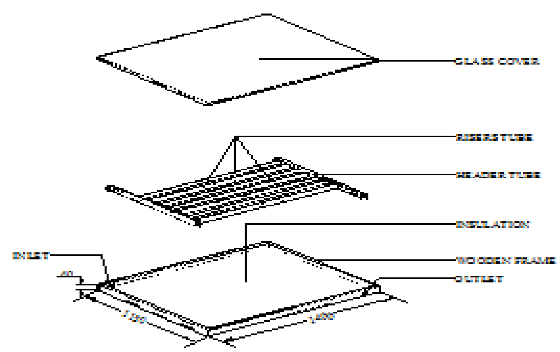

Fig. 2. Collector System.

This involved first and foremost the determination of the thermosyphon head, using Eq. 1 (Agbo and Unachukwu, 2006), in order to determine the exact height of the cold water tank above ground.

$$H_t = [\rho_o gH - \rho_i gdl]/\rho' g \quad (1)$$

Where:
H_t = Thermosyphon head
dl = length of the developing flow
H = height of tank to the collector
ρ_o = density of water at outlet of the collector
g = Acceration due to gravity
ρ_i = Density of water at the inlet of collector
ρ' = average density of the water in the system

The thermosyphon head generated was used to overcome the resistance in the circulations loop.

Heating load

The heating load refers to the quantity of water that will be required per person in a building. For this study however, the heating load was based on monthly water utilization of a family of seven people (N_p) living together in a building over a range of 30 days.

This is evaluated from Eq. 2 (Mani and Rangarajan, 2005).

$$L = N_d N_p V_p \rho C (T_m - T_a) \quad 2$$

where:
L = load required
N_d = number of days
N_p = Number of people
V_p = Volume of water required per person
ρ = density of water at required temperature
c = specific capacity of water
T_m = mean system temperature
T_a = Ambient temperature of water.

Solar collector area (A)

The area of the solar collector was evaluated using Eq. 3 (Sambo and Bello, 1992)

$$A = \frac{L}{\eta \times I} \quad 3$$

where:
η = system's efficiency
I = global solar radiation
However, the thermosyphon system's efficiency (or performance) is determined from (Agbo, 2006).

$$\eta = \frac{A F_R[Io(\alpha\tau)_e - U_L(T_m - T_a)]}{A I} \quad 4$$

Where:
A = collector Area
F_R = heat removal factor
I_o= Global Solar radiation
$\alpha\tau$ = Absorbance transmittance product

Moreover, with the knowledge that A, F_R and U_L are constants; Eq. 4 can be directly expressed as:

$$\eta_c \quad \alpha \quad \frac{(T_m - T_i)}{I} \quad 5$$

Thus from Eq. 5 it can be deduced that the performance of the thermosyphon system is directly related to the ratio of the difference in the output and input temperatures to the global solar radiation.

Tube spacing

The spacing in between two consecutive tubes bearing water to be heated is determined using (Agbo and Okeke, 2007).

$$\omega = \frac{A}{n\tau} \quad 5$$

where:
ω = tube spaing
n = number of tubes
τ = length of the collector tube

Overall heat loss from the system

The design of the system was carried out such that, its overall heat loss was very minimal. Moreover, heat losses through the system usually occur from three faces – top (side facing the sun), edge (sides of the collector) and the bottom (end view of the collector). The overall loss is related by Eq. 6 (Agbo and Unachukwu, 2006).

$$U_L = U_T + U_b + U_e \quad 6$$

where:

U_L= Overall loss coefficient,
U_T = Top loss coefficient
U_e = edge loss coefficient, U_b= Bottom loss coefficient

and

$$U_T = \left[\frac{N_G}{\frac{c\{(Tm - Ti)\}}{Tm(N_G + f)}^e} + \frac{1}{h_W}\right]^{-1} + \frac{\sigma(T_m - T_i)(T_m^2 - T_i^2)}{\varepsilon_p + 0.0059(N_G h_W)^{-1} + \frac{2N_G + f - 1 + 0.133\varepsilon_p}{\varepsilon_g} - N_G} \quad 7$$

Where: c,e,f, are constant expressed as:
f = $(1 + 0.0898 h_w \epsilon_p)(1 + 0.007866 N_G)$
c = $520(1 - 0.000051\beta^2)$ for $0^o \le \beta \le 70^o$, for $70^o \le \beta \le 90^o$ use 70^o
e = $0.43(1 - 100/T_m)$
N_G = Number of glass cover
h_W = Water heat transfer coefficient
σ = Stefan Boltzman constant
ε_p = Plate emittance
ε_g = Glass emittance

It should be noted that for a natural circulation, the edge loss coefficient is negligible which made overall coefficient U_L to be

$$U_L = U_T + U_b \quad 8$$

Also, using the relation in [8] the density of the system can be easily determined and by extension the pressure of the system is determined. The equations are expressed below in Eqs.9 and 10. However, no model evaluates the pressure of a thermosyphon system from its temperature.

$$\rho(T) = -0.00000405T^2 - 0.00003906T + 1.0002556 \quad 9$$

Where;

ρ = density

T = Temperature (^oC)

and pressure is expressed as

$$P = (\rho_{in} - \rho_{out})gH_z$$

Where;

P = Pressure 10

After complete design, construction and installation of the studied Thermosyphon system, the experiment was conducted by taking the inlet and outlet water temperature at an interval of one hour. There was no appreciable temperature difference for about an hour, because the radiation is yet to be effectively absorbed by the system. The experiment was conducted for 3 sun-off, 3 sunny and 3 moderate sunshine days. On sun-off days when the cloud overshadowed the days, the radiation took time before its effect was felt. In all the periods of the experiment it was observed that the system temperatures increased until a maximum temperature was reached, and this occurred between the same ranges of time. The behaviour and general system performance for the days of the experiment are presented using figures 1 to 5.

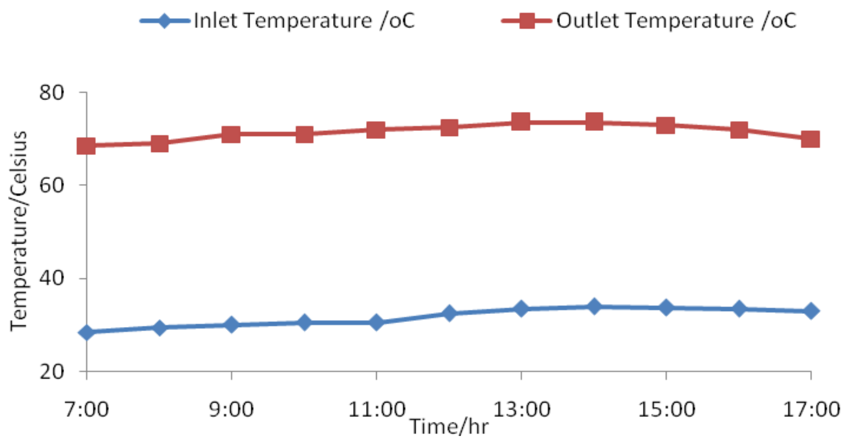

Fig. 3. Plot of Temperature against Time during Moderate Sunshine Day.

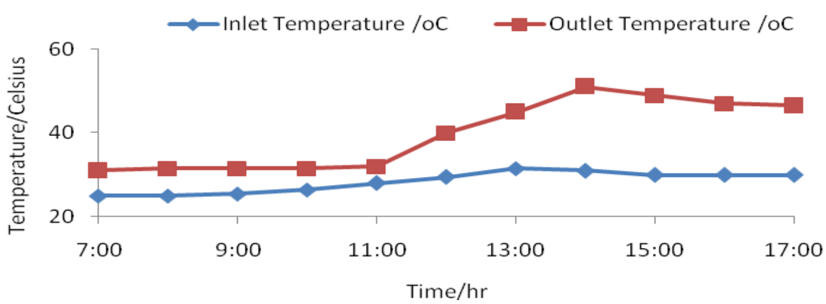

Fig. 4. Plot of Temperature against Time during sun off Day.

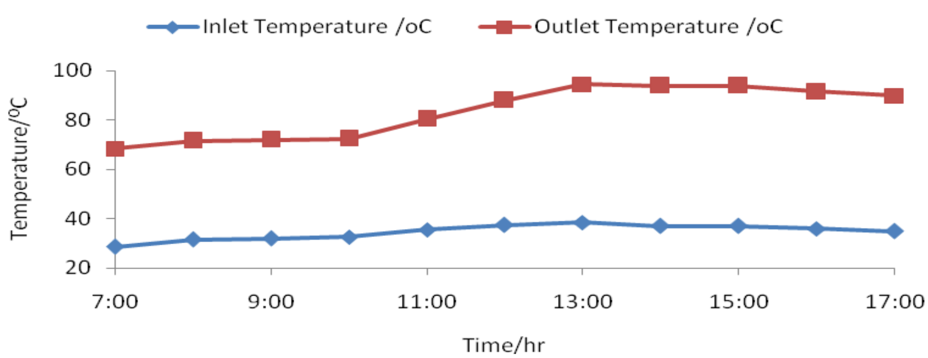

Fig. 5. Plot of Temperature and Time during Sun up day.

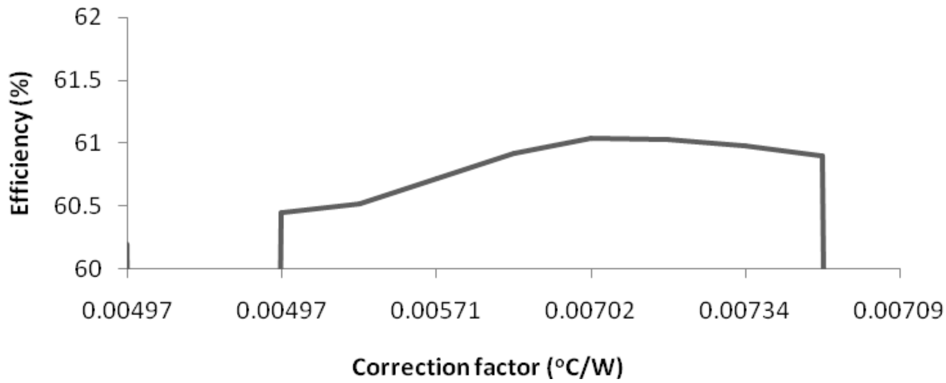

Fig. 6. Performance of Solar Collector.

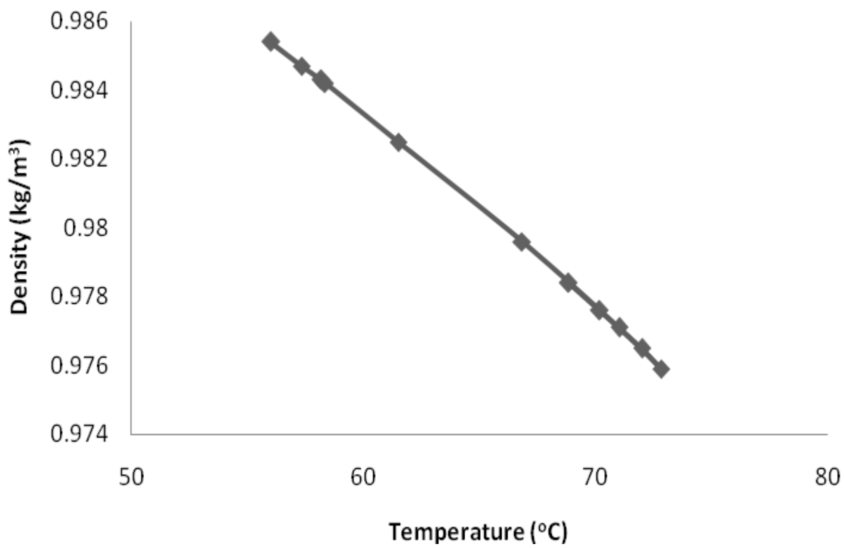

Fig.7. Plot of Density-Temperature Variations.

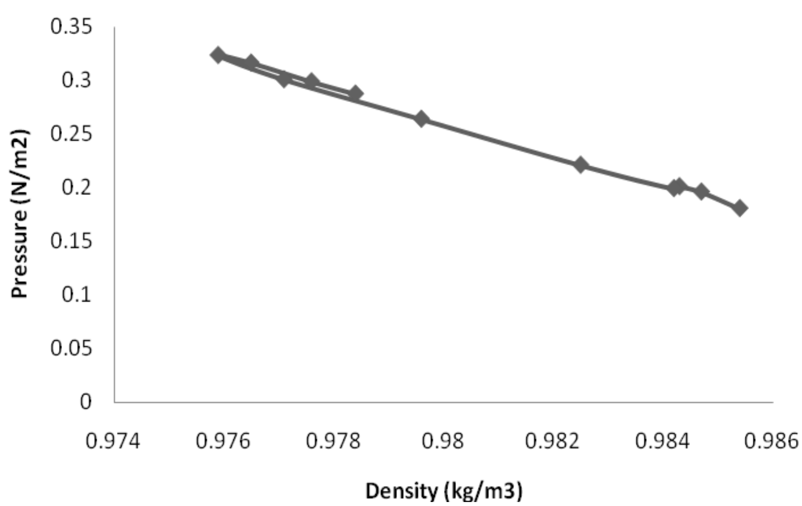

Fig. 8. Plot of Pressure-density Variation.

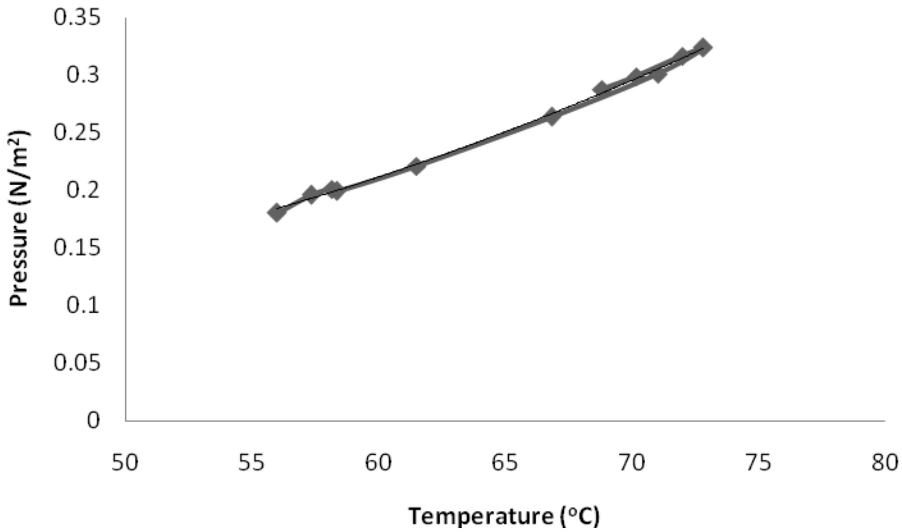

Fig. 9. Plot showing the relationship between pressure and temperature of the thermosyphon system.

RESULTS AND DISCUSSION

Figure 3 shows that the average hourly variations of the system temperature for moderate sunshine days gave a maximum system temperature of 73.50^{o}C. This according to (Fairbairn and Mario, 1999) is effective for most domestic and probably industrial needs where low pressure is required. Figure 4 however, indicates that average maximum system temperature was reached between 1.00 pm to 3.00 pm for sun off days. The maximum average value for the period gave 51^{o}C. This value is within the range reported to be effective for use as bathing, washing and sometimes for steaming purposes according to (Fairbairn and Mario, 1999).

Figure 5 on the other hand, indicates the operations of the system for sunny days. This gave the highest system performance because of high radiation intensity and its rate of absorptions, judged by the high temperature readings throughout the experiment period. Comparing the system performance between the sunny, sun-off and moderate sunshine days, it could be seen that maximum temperatures occurred during the same period, between 1.00 pm and 3.00 pm. However, due to low radiation for sun off days, the rates of absorption were low. This consequently affected the system's water temperature. While in the sunny days, the rates of absorption were high and consequently the water temperatures were high (up to 94.6^{o}C). The performance for moderate sunshine days were found to lie between those of the sun-off and sunny days. These results show that the performance of a Thermosyphon Solar Water Heater is affected by the system temperature. Worthy of note is the fact that, when the maximum water temperature of 94.5^{o}C for sunny days was achieved, the inlet temperature was 38.5^{o}C. The difference in temperature of 56^{o}C is the impact of the system on the inlet water. Moreover, (Fairbairn and Mario, 1999) reported that, a system which can add temperatures between 50^{o}C-60^{o}C is adjudged to be effective. Based on this, the thermosyphon water heating system of this study was found to be effective.

In order to determine the efficiency of the developed thermosyphon system, Eqs.4 and 5 were employed and the result gave in figure 6. Here figure 6 shows that the highest efficiency of 61.04 % was obtained and this demonstrates good performance. More important to this study is the period of the experiment, which was in June (a month within the rainy season in Nigeria). During this period, there is always low radiation intensity, high cloud cover leading to more scattering of global solar radiation. The efficiency is expected to be higher in the dry season (October to March) when temperature is always high and very low cloud cover.

Furthermore, it was discovered that the efficiency increased with time up to 3:00 pm after which it dropped to lowest 60.81%. The decrease in performance was caused by the effect of its loss factor, [U_L(Tm-Ti)], which occurred as outlet temperature reduces. However this may be improved upon by better material selection. The effects of system temperature and ambient parameters showed clearly the direct variation with hourly efficiency. This was also confirmed by (Agbo *et al*., 2005).

Moreover, the knowledge of the values of the system temperature can aid in the knowledge of the other system parameters of density and pressure and by extension their relative effects. Figures 5 to 7 give the relative values of the system's parameters. However, figures 5-6 reveal inverse relationship between density and temperature as well as between pressure and density. Figures 7 shows that while the temperature increased from 56 to 72.8°C, the density varied marginally from 0.99 to 0.98 kg/m^3. Thus showing that, temperature changes have a marginal effect on the density variation of water in the thermosyphon system. Further to this, Fig. 8 shows the variation between pressure of the system and density of the water. This reveals that a minimal increase of density from 0.98 to 0.99 kg/m^3 led to a decrease of 0.14 Pa (from 0.32 to 0.18 Pa). This invariably showed that while temperature greatly affects the pressure of the system, the density is marginally affected.

Therefore, finding the relationship between pressure and temperature buildup in the thermosyphon system (Fig. 9). Figure 9 clearly demonstrates a quadratic relationship between the parameters. Thus, a regression analysis of pressure of the thermosyphon system against its temperature buildup gave Eq. 11. The standard error is small enough to make the model as fitted acceptable.

$$P(T) = 0.0001T^2 - 0.006T + 0.1738$$

(R^2-value = 0.998, e = 0.003) 11

where:
R^2 = coefficient of determination
e = standard error

Eq. 11 thus is a model explanation of the inter-relationship between pressure and temperature in a thermosyphon system. The R^2 statistics reveal that the model as fitted explains 99.8% of variability in pressure, at 95% confidence level, as it depends on the system's temperature.

Correlating the three parameters to determine the exact cumulative effect of temperature and pressure on density gave Eq. 12.

$$\rho = 1.0118 - 0.0004T - 0.0177P$$

(R^2 = 99.97%, e = 7.53 x 10^{-5}) 12

Therefore, Eqs 11 and 12 can be employed to determine the parameters of the thermosyphon system without necessarily the need of a repeated experiment.

CONCLUSION

The study has been used to evaluate the relative effect of temperature on a thermosyphon solar water heater. It established that a thermosyphon system performs adequately with optimum efficiency and temperature of 61.04% and 94.5°C respectively. Also comparing results with the previous studies, a more accurate and higher temperature was achieved. This is because the data were evaluated based on the average values of the various days considered instead of on a one day experimental period. The temperature of 51°C was obtained during peak period of sun-off day. This simply shows that usable hot water could be made available all year round and that a higher system temperature has been achieved compared with the previous experiments. This study has therefore been used to determine the exact effect of system temperature on the performance of a thermosyphon water heater. The study was also able to evaluate the relative effects of pressure and density as they depend on the system's temperature. Further to this, the study developed new models that correlate temperature and pressure and also temperature, pressure and density.

Table1. List of component parts according to the labelling of figure 1.

Key	Name	Qty	Materials
1	By pass valves	3	Brass
2	Hot water tank	1	Galvanise steel
3	Hot water pipe	1	Galvanise steel
4	Collector assembly	1	Glass, wood, collctor
5	Support stands	1	Mild steel
6	Inlet pipe	1	Galvanised steel
7	Non returned valves	1	Brass
8	Pipe line	1	Galvanise steel
9	Elbow joint	4	Galvanise steel
10	Collector support	1	Wood
11	Cold water tank	1	Galvanise steel
12	Riser pipe	7	copper
13	Tank supports	1	Mild steel
14	Cold water tank	1	Galvanise steel
15	Header pipe	2	copper
16	Dull black paint		
17	Collector	1	Galvanise steel

REFERENCES

Adegoke, CO. and Bolaji, BO. 2000. Performance evaluation of solar operated thermosyphon solar hot water system. Int. J. Engineering and Engineering Technology. 2:35-40.

Agbo, SN. 2006. Effect of hot water withdrawal rate on a mean system temperature of a thermosyphon solar water heater, The Pacific Journal of Sci. and Technology. 7:33-42.

Agbo, SN. and Okeke, CE. 2007. Correlation between collector performance and the tube spacing for various absorber plate materials in a natural circulation solar water heater. Trends in Applied Science Research. 2(3):251-254.

Agbo, SN. and Oparaku, OU. 2006. Positive and future prospect of solar water heating in Nigeria. The Pacific Journal of Sci. and Technology. 7(2):191-198.

Agbo, SN. and Unachukwu, GO. 2006. Performance evaluation and optimization of ncerd thermosyphon solar water heater. Proc. World renewable Energy Congress Aug. 19-25, Florence, Italy.

Agbo, SN., Unachukwu, GO., Enibe, SO. and Okeke, CE. 2005. Solar energy heating for residential university student. Nigeria Journal of Solar Energy. 15:85-89.

Beckman and Duffie. 1991. Solar Engineering of Thermal Process, (2nd ed.), John Wiley and Son, New York, USA.

Chang, JM., Leu, JS., Shen, MC. and Hang, BJ. 2004. A proposed modified efficiency for thermosyphon solar water heater system. Solar Energy. 76:693-701.

Fairbairn, P. and Mario, R. 1999. Solar water heater, a SOPAC Technical Reports. (unpublished).

Morrison, GL. 1986. Solar domestic water heater design sensitivity study, Report No 1986/FMT/2 (unpublished).

Mani, A. and Rangarajan, S. 2005. Solar radiation over India. Solar Energy. 15:131-126.

Rasheed, KB. 1995. Participatory forestry as a strategy for reforestation in Bangladesh. Geo Journal. 37:39-44.

Sambo, AS. and Bello, MB. 1992. Simulation Studies on Pipe Spacing for a Collector and Tank for Solar Water Heaters. Nig. J. of Solar Energy. 9(3):215-223.

Received: Sept 16, 2011; Accepted: Dec 27, 2011