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PERFORMANCE OF A LOCALLY DESIGNED SOLAR WATER HEATER (SOLAR WATER KETTLE)

Sanusi Y. K. and Ajadi D.A
Department of Pure and Applied Physics
Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
Email: sanusiyekinni@yahoo.com

ABSTRACT

A Built-in-Storage Solar Water Heater of 4.5×10^{-3} m^3 liter was designed, constructed and tested for its efficiency. It was observed that the highest temperature of the water obtained is 48^oC. This temperature was achieved between the hours of 16.00 and 16.30 hours local time. The efficiency of the kettle was found to be 1.65%, which is very small due to the construction size. When compared with previous work, the solar water heater that produces up to efficiency of 30% has surface area of $2.6m^2$ while in this work surface area is $0.15m^2$.

Keywords: Temperature, Heater, Solar radiation, Efficiency, Absorber plate.

INTRODUCTION

The source of energy (Gate, 1986) solar radiation is free but the equipment needed to persuade the solar rays to do useful work can sometimes be expensive, usually requires maintenance and needs certain understanding of how things work. One of the beautiful characteristics of solar equipment is that it can be made in varying degrees of perfection and in a wide range of sizes and costs. This implies that it can be of use for a wide social range of people as well, from the farmer who dries his grains; to a medical doctor or nurse in the hospital that uses a solar water heater for domestic usage in the sterilization of water and of medical instruments (Tool, 2002). Solar water heaters can thus replace wood used for rural water heating, oil – fueled boilers and expensive electric water heaters (Hnakins, 1995).

As part of the progress made, it has been shown that the simplest and most practicable out of solar energy utilization is the concept of a flat – plate collector and its use for drying and heating purposes (Ackerman, 1915; Bahadon, 1977; Duffie and Beckman 1974). The flat – plate collector has been in use both in developed and developing countries for heating and cooling houses, and to provide hot water (Sabbagh and Sayigh, 1973), for domestic uses. Other solar energy utilization systems include solar cells and photo – thermal converters, which are very expensive to make (Seraphin 1976; Meinel and Meinel 1976). As of 1995, there were more than 30,000 square meters of installed solar heaters in Kenya, Botswana, and Zimbabwe alone. In Botswana, solar water heaters produce the equivalent of almost 10% of the domestic electric energy demand (Hankins, 1995).

In view of the economic involvement and its simple construction, which does not require any intense maintenance, simple solar water heater designs have more immediate applications in Nigeria, especially places where there are no pipe borne water systems or electricity. In this paper a simple solar water kettle was constructed from locally available materials and its efficiency determined.

DESIGN, CONSTRUCTION AND TESTING

In designing any solar water heater, two broadly factors are of importance, these are the technical and the socio – economic factors. A solar heater must be designed with simple feature and cost to gain wide and quick acceptance by the common people. The type of solar Water heater used in this work is the Built-in- Storage. Here there is no separate storage tank in this design. The absorber plate performs dual function of absorbing the solar radiation and storing the solar heat. This type is now typed as solar water kettle, since the hot water is static and is meant for use within a short time.

The kettle consists of glass cover; absorber plate; casing as container; tank to contain the water 4.5×10^{-3} m^3; reflective mirror by the sides of the tank; and a tap to remove the hot water from the tank. Figure 1 shows the prototype of the constructed solar kettle.Figure 1: Prototype of the solar kettle designed for use.

The solar kettle was tested by placing it in an open space on a horizontal plane to receive both direct and indirect solar radiation. The solar radiation passes through the glass collector-heating interior of the casing by greenhouse effect. The heat inside the casing then reflected to the tank with the aid of two inclined mirrors, which tend to heat the water content inside the tank. Measurement of the ambient temperature T_a, absorber temperature T_b, and temperature inside the tank (T_e and T_w) were taken respectively. Where T_e is the temperature of the empty tank and T_w is the temperature of the tank when full of water. The result is presented in Table 1.

RESULTS AND DISCUSSION

Table 1: Reading of the various temperatures.

Time	T_a	T_b	T_e	T_w
0	25	26	26	25
30	25	27	28	25
60	26	30	33	27
90	27	33	38	29
120	28	36	41	32
150	29	39	43	35
180	29	41	47	37
210	30	43	50	41
240	31	46	52	42
270	32	48	54	42
300	33	52	55	43
330	34	55	56	44
360	34	55	57	45
390	35	56	59	46
420	35	57	59	48
450	34	57	58	48
480	34	57	58	47

Time	dT
0	1
30	4
60	10
90	19
120	28
150	36
180	46
210	55
240	65
270	75
300	87
330	97
360	109
390	122
420	133
450	143
480	154

Table 2: Cumulative excess temperature of empty kettle over water in the tank.

Time	dT/dt
0	0
30	0.13
60	0.17
90	0.21
120	0.23
150	0.24
180	0.26
210	0.26
240	0.27
270	0.28
300	0.29
330	0.30
360	0.31
390	0.31
420	0.32
450	0.32
480	0.32

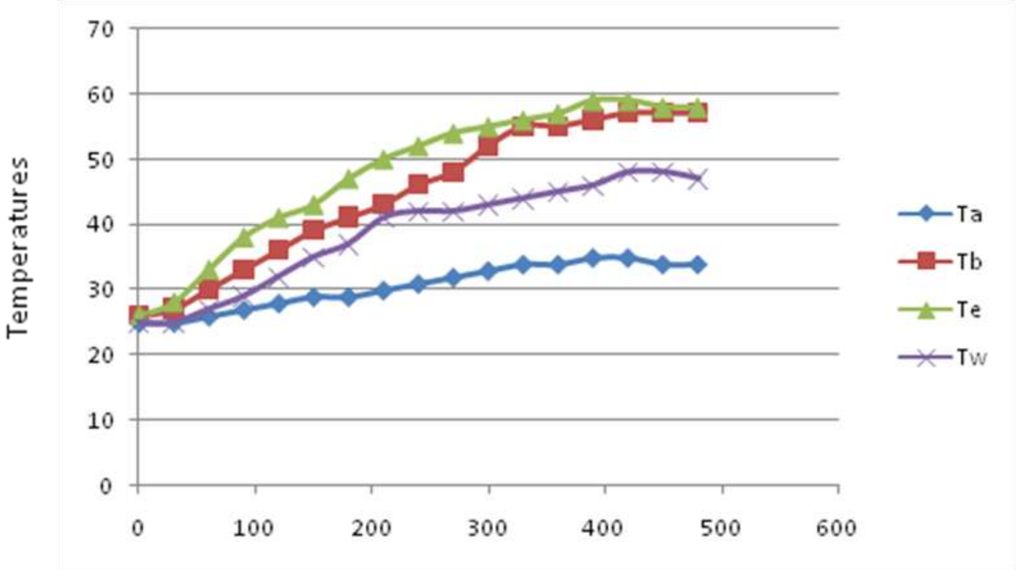
Table 3: Rate of heating water inside the kettle

From table 1, the cumulative excess temperature of empty kettle over full water inside the kettle, and the rate of heating the water were obtained and presented I table 2 and 3 respectively. Again from table 1, the recorded readings show that the temperature of the empty kettle is higher than that of the absorber at any given time of the day. As expected, the temperature of the water inside the kettle is lower than the temperature of the absorber and the empty kettle at any given time of the day. Whereas the temperature of water is quite higher than the ambient temperature. The rate of heating water increases very slowly, since the water in the kettle is of fixed volume and static. This is as expected since water of fixed volume traveling through a long heated pipe will have ability to absorb more heat energy to have higher temperature.

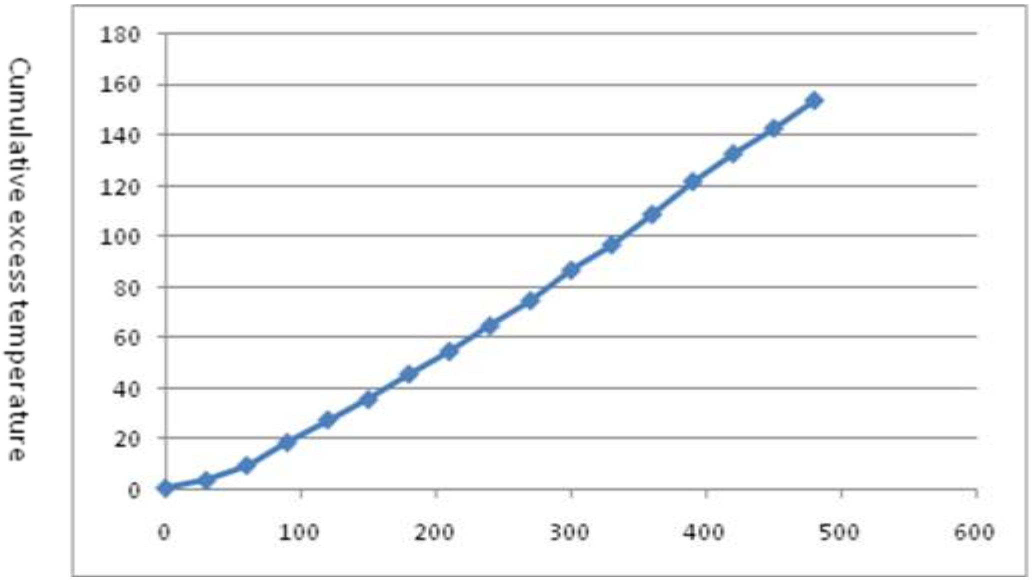
As expected, the graph in figure 1 shows that the characteristics temperature curve of empty kettle is high followed by the absorber, and then followed by that of water while the ambient curve shows the lowest. The reliability of the curve fittings has an average value of 0.99. The equation of each curve is given by equation 1 through equation 4.

For T_e: $T = -0.0001x^2 + 0.1478x + 25.059$ $R^2 = 0.9965$
For T_b: $T = 0.0002x^2 + 0.0636x + 25.695$ $R^2 = 0.9965$
For T_w: $T = 2e^{-0.5}x^2 + 0.0755x + 23.448$ $R^2 = 0.9840$
For T_a: $T = 0.0001x^2 + 0.1478x + 25.059$ $R^2 = 0.9965$

Figure 2 illustrates the graph of cumulative excess temperature of the empty kettle over temperature of the water against time; this shows a perfect curve fitting with reliability of 0.9997. The corresponding equation of the curve fitting is given by equation 5.
For T_w: $T = 0.0006x^2 + 0.1625x + 0.2147$ $R^2 = 0.9997$

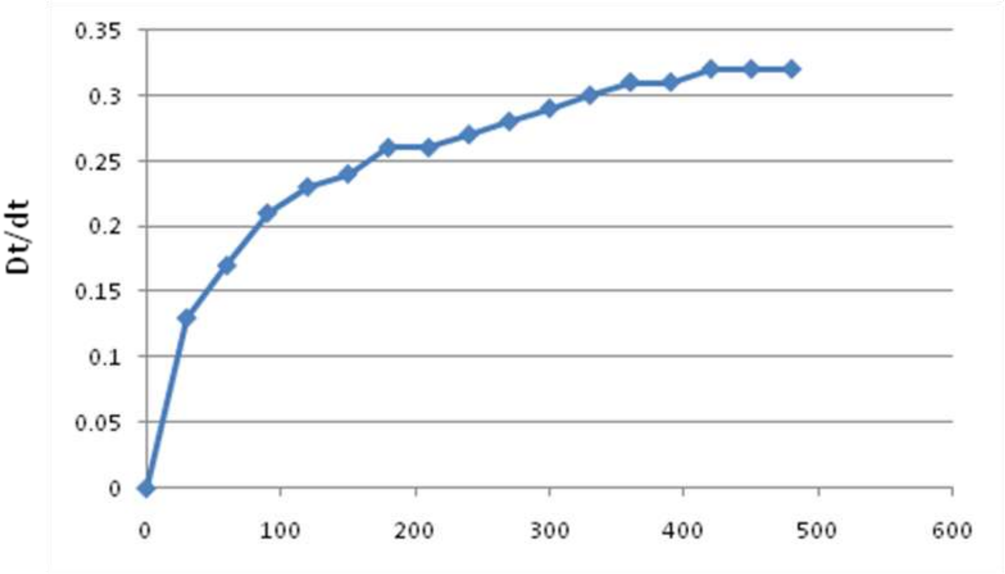


Time of the Day (Minutes)
Figure 1 Temperature - Time Characteristics Curves



Time (Minutes)

Figure 2 - Cumulative Excess temperature of Empty Kettle



Time (Minutes)

Figure3: Rate of heating Water (dT/dt)

The graph of the figure 3 shows the rate of heating water inside the kettle. The equation of the curve fitting is given by equation 6.

$y = -2\,e^{-05x^2} + 0.0036x + 0.014$ **R^2 = 0.9900……………….**6

Calculation of the Efficiency of the Kettle

The heat gain by the water is given by: $Q = mC_w(T_f - T_i)$............................7

Where m is the mass of the water; C_w is the specific capacity of the water and T_i and T_f are the initial and final (highest) temperature of the water respectively. The mass of water is given as m = ρV; where ρ is the density of water equal to 1.0×10^3 kgm^{-3} and V is the volume of the water contained in the kettle which is equal to 4.5 liters = 4.5×10^{-3} m^3. The efficiency of such kettle according to Akomolafe (1991) can be defined as:

$$\eta = \frac{Q}{I_{total}} \times 100\ \% \qquad \text{..8}$$

where η is the effciency; Q is the heat gained by a particular volume of water for a fixed period of total insolation on collector; and I_{total} is the total insolation given by 275.11 kWm^{-1} for the experimental site. Combining equations 7 and 8; then substituting the values of the symbols we have:

$$\eta = \frac{\rho V C_w (T_f - T_i)}{I_{total}} \times 100\ \%$$

$$\eta = \frac{1.0 \times 10^3 \times 4.5 \times 10^{-3} \times 4.2 \times (48.0 - 25)}{275.11}$$

$$\eta = 1.65\ \%$$

This value is rather too low when compared with work already done. According to Hislop (1992), water is usually heated by burning fuel. An oil (kerosene) or gas fuelled water heater achieves an efficiency of about 50%; while heating on an open fire has an efficiency of only about 10%. By comparison a simple solar water heater might have an efficiency of about 30%. On a sunny day solar energy

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