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Solar Water Heater: Black Versus Transparent Hosepipe Heat Absorbers

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Abstract: *We have compared the performances and efficiencies of solar water heatersconstructed using coiled black and coiled transparent hosepipes.The two hosepipes were equivalent in length and diameter measuring about 50 yards (45.7m) and 1 inch (2.5cm) in diameter. Theyconstituted the heat absorbers of the solar collector system in which water was pumped and cycled continuously in the hosepipe by a dc water pump powered by photovoltaic (PV)panels. The 50 yard long hosepipe (black or transparent) wasformedinto a circular flat coil of about 20 turns inside a shallow rectangular box and covered with a transparent glass/plastic sheet.The waterpump draws water from the bottom of a reservoir, runs it through the coiled hose and discharges it back into the reservoir from the top.In this process the sun heats up the hose through solar radiation and the pipe heats up the water through conduction. We investigated whether a black hose is more efficient in heating the water than a transparent hose and found no significant difference.The explanation lies in the factthat when the hose is contained in the glass covered box, the water heating process is dominated more by greenhouse radiation than by direct radiation. Hence it is immaterial whether the hose is black or not.Thisinvestigation was carried out in the month of January and February and the location was Owerri, South East Nigeria.*
Keywords: *Hosepipe, Water heater, DC water pump, Solarcollectors, Greenhouseeffect*

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I. Introduction

Solar collectors transform solar radiation into heat and transfer that heat toa medium (water, solar fluid or air). Flat-plate collectors are the most widely used kind of collectors for domestic water heating systems(Paul, 1979). A typical flat-plate collector consists of an absorber, an insulator box and one or more transparent cover sheets.

The absorber is usually a sheet of high thermal conductivity metal such as copper or aluminum with tubes either integrated or attached. The absorber surface and the interior of the insulator box are usually coated black supposedly to maximize radiant energy absorption *(*Agbo *et al*, 2005; Enibe, 2007; Ojosu & Komolafe, 1989; Sambo & Bello, 1990). The insulated box reduces heat loss from the back and the sides of the collector. The transparent cover sheet allows sunlight to pass through to the absorber and reduces upward heat losses by convention. The transparent cover also acts like the glass in a *greenhouse*. It increases the heat generating infrared radiation inside the greenhouse (Giambattista *et al*, 2007); in this case the insulator box.

In this work, we use a coiled hose pipe as the heat absorber in the solar collector system. Previously, researchers have always coated the collector (everything inside the insulator box) in black, believing it to maximize solar heat absorption (Boeker & Van-Grondelle, 1999; Mgbenu et al, 1995). Recently, black coiled hose has been employed in solar pool heating with an ac-water pump (Mbamala et al, 2017; Mbamala & Wokoma, 2017) and with dc-water pump(Mbamala, 2018). The heating efficiencies of these systems have been very encouraging. Here, we wish to investigate whether the color of the hose (the heat absorber) is really important by comparing the efficiencies of solar water heaters designed with black and transparent coiled hose pipes. For the transparent hose system, we cover the inside of the insulator box with shiny aluminum foil thereby removing any trace of black coating. The result of this investigation will be a good guide in the choice of materials in designing solar pool heaters. We note that transparent hoses of various sizes are more in abundance than black hoses in the market.

II. Methodology

Solar water heating involves the conversion of sunlight into thermal energy.An active solar water heater consists of three major component systems, namely: the collector, the water pump and the water storage systems (Paul, 1970).The three components are shown schematically in Fig. 1

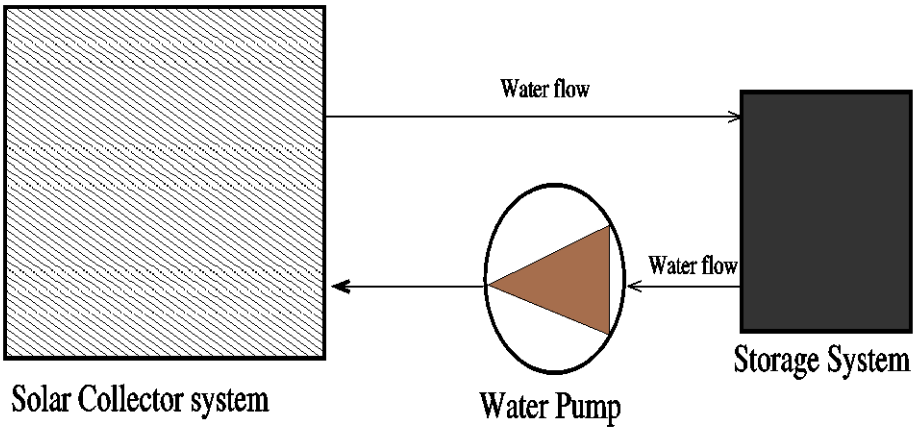

Figure 1: *Block diagram of an active solar water heater showing the collector, pump and storage systems.*

The Water Storage System

The water storage system consist of a 120 liter plastic reservoir and a rectangular wooden box. The reservoir is placed inside the wooden box and the space between the container and box filled with sawdust. The sawdust provides heat insulation to the water container to reduce heat loss. The details have been described elsewhere (Mbamala, 2018)

The Water Pump System

The system is comprised of a dc water pump, a rechargeable battery, a solar charge controller and a photovoltaic (PV) panel. The dc pump is powered by the battery while the PV charges the battery. The full description of the dc water pump system was made by Mbamala (2018).

The Collector System

The main focus of this study is on the collector system. A 50-yard (45.7m) long hose was coiled to about 20 turns inside a shallow wooden rectangular box (insulator box) mounted on a metal stand (see Fig 2). The coil formed a circular 'flat' surface of diameter 1.12m. The box (with the coiled hose inside it) was then covered with a 2mm thick transparent plastic sheet. The flat coil and the covered box constitute the solar collector.

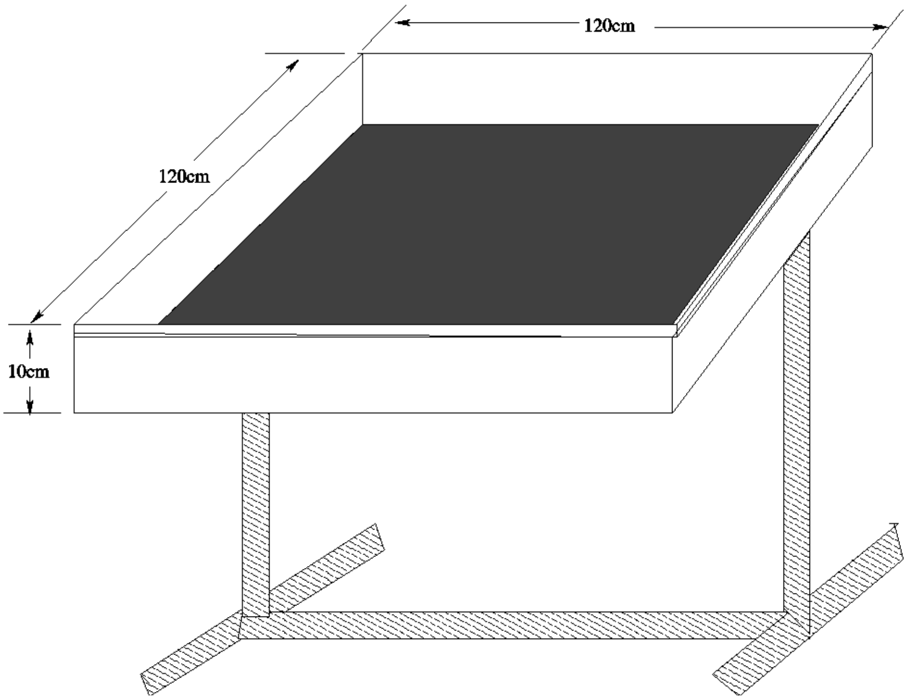

Figure 2: *The shallow rectangular box mounted on a metal stand inside which the hose is coiled.*

Figure 3 (a) and (b) show the complete collector systems for a black hose and a transparent hose respectively

As stated earlier, the plastic cover acts like the glass in the greenhouse. When sunlight falls upon the glass, most of the visible radiation and short wavelength infrared (near-infrared) travel right through the glass because the glass is transparent to those wavelengths. The radiation transparent to the glass is absorbed by the black hose to heat up the circulating water. This form of heating also occurs in the absence of the glass covering. Since the inside of the glass (greenhouse) is much cooler than the sun, it emits primarily infrared radiation (IR). The glass is not transparent to the longer wavelength IR; much of it is absorbed by the glass. The glass itself also emits IR, but in both directions: half of it is emitted back inside the 'greenhouse'. This absorption and emission of IR keep our *greenhouse collector* warner than it would otherwise be (Boeker & Van-Grondelle, 1999; Giambattista *et al*, 2007).

Figure 3(a): Black hose solar collectoe

Figure 3(b): Transparent hose solar collector

Thermal Efficiency calculation.

We calculate the efficiencies of the two collector system (black and transparent) to see how much greenhouse contributes to the water heating.The thermal efficiency of the entire system, ηcan be calculated as the ratio of the useful power gained by the collector, P_u to thetotal input powerto the system, P_i

$$\eta = \frac{P_u}{P_i} \times 100\% \qquad (1)$$

The quantity

$$P_i = P_c + P_{wp}\,, \qquad (2)$$

whereP_c is the total solar radiant power incident on the collector and P_{wp} is the electric power of the water pump.

$$P_c = I_s \mathrm{A} \quad , \qquad (3)$$

where$I_s$is the intensity of solar radiation in W/m^2, incident on the plane of the solar collector having a collector surface area Ain m^2. In our system (see Fig. 4),

$$A = \pi(R^2 - r^2) \qquad (4)$$

Aisthe area defined by the radius of the coil$R$ minus the area not covered by the coil at the center (radius, r).

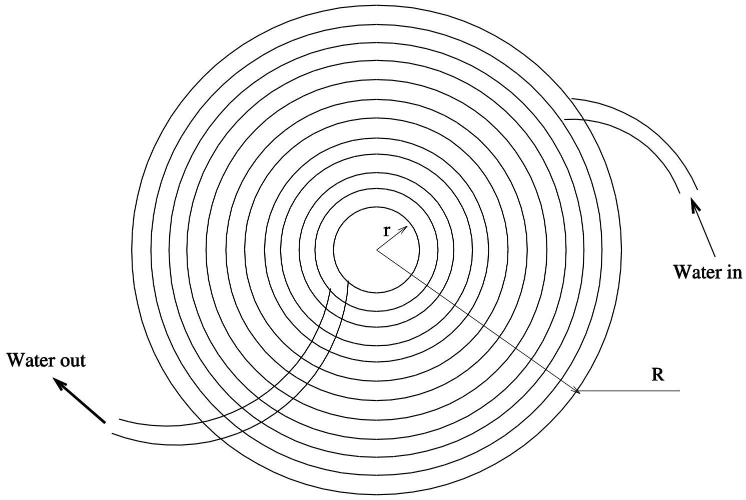

Figure 4: Schematic diagram of the coiled hose showing the inner radius r and the outer radius R used to obtain its surface area.

In practice, P_u can measured by means of the amount of heat carried away in the fluid passed through the collector, that is;

$$P_u = mc \vartriangle T/\vartriangle t, \qquad (5)$$

where c is the specific heat capacity of the fluid of mass m, $\vartriangle T$ is the change in temperature of the fluid over a time interval $\vartriangle t$.

III. Results and Discussion

Our main objective is to compare the performances of black and transparent coiled hoses as components of solar collectors in the design and construction of active solar water heater and similar devices. Measurements and evaluation of the systems were carried out between the months of January and February. Quantities measured include: the temperature of water at any time, $T_w$and the ambient temperature during measurement,T_a. We also measured the intensity of solar radiation during this period using a pyrometer. In each test, the initial volume of water was kept at 100 liters. These quantities enabled us to determine the efficiencies of the device with black hose and transparent hose.

Figure 5 shows how the measured temperatures namely, the water temperature $T_w$and the ambient temperature T_a vary with time of the day, for the black hose and the transparent hose. The time of the day started from 10:00am and ended at 5:00am the following day (i.e. 29 hours). However, the water pump was switched off at 6:00pm. For the black hose, a peak water temperature of 47^{o}C was recorded between 3:30pm and 4:00pm, while for the transparent hose the peak T_w was 46^{o}C at the same time period. This is only a difference of 1^{o}C.The ambient temperatures for the two cases were close until later in the day and late into the night. $T_a$for the black hose dropped to 19^{o}C by 5:00am the following day, while at the same time, for the transparent hose, it dropped to about 26^{o}C. That perhaps explains why $T_w$for the black hose dropped slightly faster than for the transparent hose in spite of the higher peak for the black hose. We recall that heat insulation was

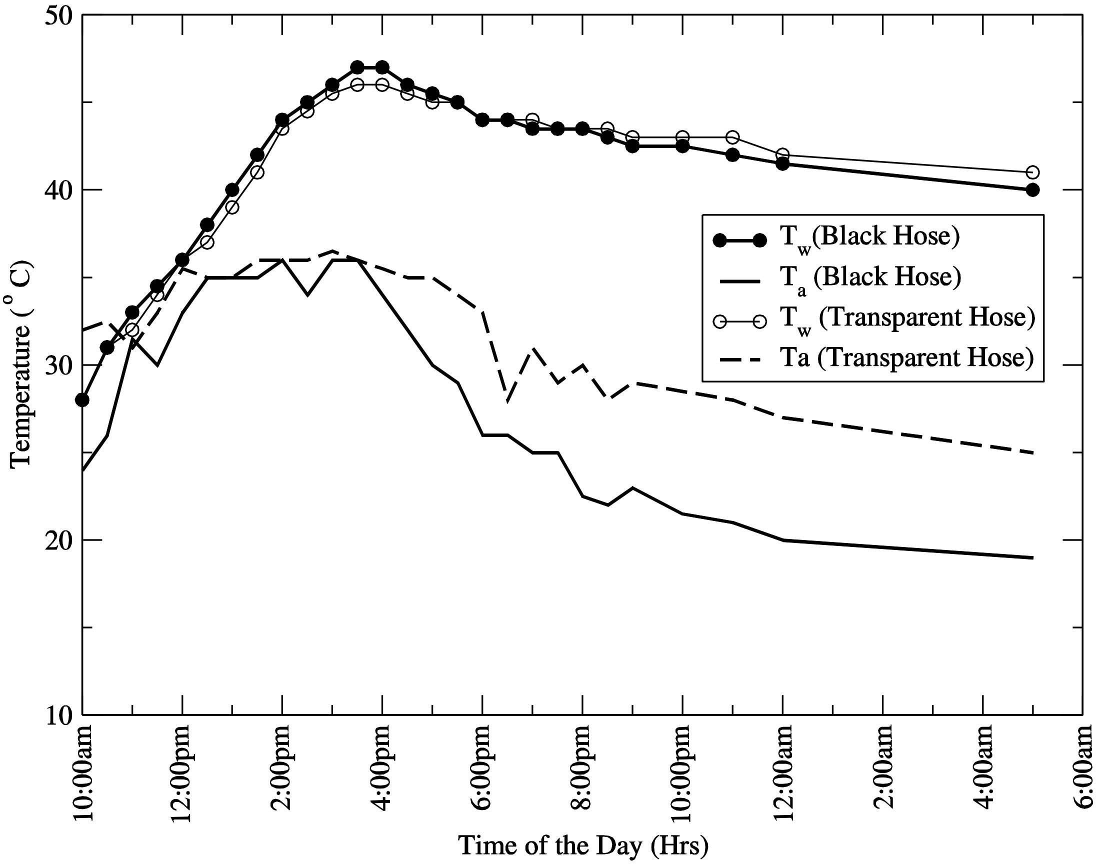

***Figure 5**: Plot of the water temperature T_w and the ambient temperature T_a against time of the Day; for the Black hose and the transparent hose.*

provided for the water reservoir and that explains the very slow drop from the peak in T_w for both cases; 47°C to 40°C (black hose) and 46°C to 41°C (transparent hose).

Efficiency

We determined the efficiency of each system using eqs. (1) to (5). We denote the efficiency of the black hose system by η_{bk} and that of the transparent hose by η_{tp}. In eq. (1), we assume the total input power P_i to be the same for both the black and transparent hose devices. From eq. (4), the surface area of the coils (black or transparent) $A = 0.986m^2$. The average intensity of solar radiation for the test location and period was determined to be $I_s = 700.0Wm^{-2}$(see Fig. 6). Hence from eq. (3) $P_c = 690.20W$. The output electric power of the dc water pump used is $100W$. Therefore eq. (2) gives $P_i = 790.2W$.

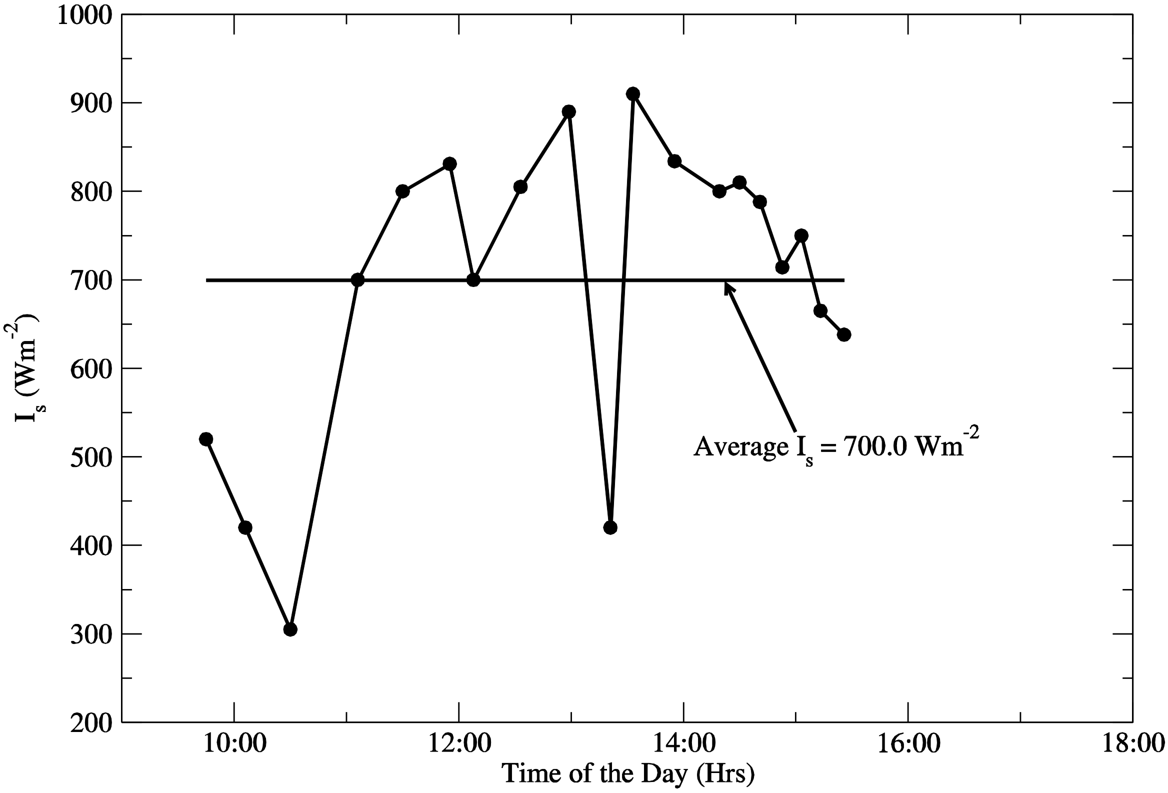

Figure 6: *Determination of average daily solar radiation Is using Hand Pyronometer 4890.20 (by FrederiksenSolData Instruments).*

To calculate P_u from eq. (5), we set $\Delta T = T_2 - T_1$, where we take T_2 to be the peak water temperature and T_1 to be the water temperature before circulation. Also let $\Delta t = t_2 - t_1$, where t_2 and t_1 are the times corresponding to T_2 and T_1 respectively. Also in eq. (5), the specific heat capacity of water, $c = 4200Jkg^{-1}K^{-1}$ and for a 100 liters ($100dm^3$) of water, $m = 100kg$.

Efficiency of the black hose system

For the black hose system, $T_1 = 28^oC = 301K$ and $T_2 = 47^oC = 320K$ to give$\Delta T = 19K$. Correspondingly, $t_1$and t_2 are respectively10:00hrs and 15:30hrs so that$\Delta t = 1.98 \times 10^4 s$.Equation (5) gives$P_u = 403.03W$. Therefore from eq. (1), the efficiency for the black hose system is$\eta_{bk} = 51.0\%$.

Efficiency of the transparent hose system

For the transparent hose system, $T_1 = 28^oC$, $T_2 = 46^oC$ and$\Delta T = 18^oC$ $(= 18K)$. Also, $t_1$and t_2 are respectively10:00hrs and 15:30hrs giving$\Delta t = 1.98 \times 10^4 s$.For this system,$P_u = 381.81W$. Again, from eq. (1), the efficiency for the transparent hose system is$\eta_{tp} = 48.3\%$.

The foregoing efficiency calculation shows that $\eta_{bk}$is slightly higher thanη_{tp}. However, that is not enough to conclude that the black hose is more efficient than the transparent hose in heating the water. This slight advantage recorded by the black hose may easily be cancelled under different weather conditions. Hence we conclude that with the type of solar collector system used in this study, it is immaterial whether one uses black or transparent hose. The explanation is that when the hose is contained in the glass covered box, the water heating process is dominated more by *greenhouse* radiation than by direct solar radiation. We recommend that further investigation be carried out to ascertain this by operating the system with exposed coil solar collector as shown in Fig. 7. This would ensure no greenhouse effect.

Figure 7: *Exposed coiled hose solar collector* (Hare, 2014).

IV. Summary and conclusion

We investigated whether a black hose is more efficient in heating the water than a transparent hose. With the black hose, we recorded a peak temperature of 47^{o}C from initial water temperature of 28^{o}C of volume 100 liters. This gave a heating efficiency of 51.0%. For the same volume of water, the efficiency of the system with a transparent hose was found to be 48.3%. Within the limits of measurement errors and environmental effects (the investigation was made on different days)the difference in the efficiencies could be said to be insignificant. We attempt to explain this result in the light of the glass covered box. It seems the water heating process is dominated more by *greenhouse* radiation than by direct radiation --- hence it is immaterial whether the hose is black or transparent. Moreover, transparent hoses of various sizes are more available and affordable than black hoses in the local markets. This work was carried out in the months of January and February (both months have similar weather conditions) and the location was Owerri, South East Nigeria.

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