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Research Article

Comparative Study of the Thermal Performance of Two Thermosiphon Solar Water Heaters System

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ABSTRACT. The aim of this study is to present the comparative results of experimental investigations of the thermal performance of two thermosiphon solar water heaters system (SWHS). The first uses the coconut fiber (CF), a local vegetable and the second, the glass wool (GW), an imported and expensive material, as thermal insulations. The maximum instantaneous efficiencies are, respectively, 65.30 % and 58.7% with glass wool and coconut fiber while the mass flow rate values are, respectively, 0.0098 kg/s and 0.0078 kg/s with glass wool and coconut fiber. In addition, the calculated average values of F'(τα) and F'UL are, respectively, 0.79 and 5.86 Wm-2°C for the coconut fiber collector and 0.8 and 5.26 Wm^{-2}°C for the glass wool collector. The average heat exchanger effectiveness obtained for the two SWHS are superior to 50%. As an environment-friendly and renewable material, coconut fiber is particularly suitable for thermal insulation in order to save energy. The experimental results show the ability of the constructed solar water heater in providing hot water suitable for maternity, hotels, households and encourage its implementation and utilization on a broad scale. The SWHS can be used in any weather conditions. ©2020. CBIORE-IJRED. All rights reserved

Keywords: Thermal conductivity, Coconut fiber; Glass wool; Heat exchanger; Thermal performance.

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1. Introduction

Solar energy arriving on earth is the most fundamental renewable energy source in nature. Renewable energy sources provide access to a secure and environmentally sustainable supply of energy in the world. Renewable energy is preferred because it is abundant, free, inexhaustible, and non-polluting. From the sustainable development point of view, it is the most sustainable energy resource (Bouraiou *et al.*, 2020; Mnasri *et al.*, 2020). Solar energy technologies offer a clean, renewable and domestic energy source, and are essential. The most popular method to benefit from the solar energy is to use solar water heating. Solar water heating is a device, which collects and uses solar heat energy to supply partially or entirely the domestic needs with hot water.

Many research works had been carried out to improve the thermal effectiveness of the solar water heater. Some of the important research is provided below. Resk*et al.* (2019) investigated the theoretical and experimental performance of a newly combined system (Tubular Daylight Device and Solar Water Heating). A novel proposed system was implemented to convert solar energy into two useful energies; light and heat simultaneously under climatic circumstances of Egypt with the same occupied space. Yassen *et al.* (2019) examined the performance of an integrated solar water heater with a corrugated absorber surface. An integrated solar water heater was built and experimentally tested outside so as to observe the temperature variation of water in the storage tank. Touaba *et al.* (2020) proposed a novel solar water heater system. Its flat plat collector uses waste engine oil as absorber and heat transfer fluid at the same time, and it is equipped with a controlled sun tracker photovoltaic system to maximize the collected solar irradiation. Mandal and Ghosh (2020) investigated the performance of a Double Pass Solar Water Heater with reflector. The influence of the mass flow rate on the outlet temperature, thermal performance, and overall performance had also been analyzed.

Most of the SWHS studied in the literature use the glass wool or synthetics fibers that made industrially as heat insulation. The objective of the study is to conceive a cheap yet efficient flat plate solar water heater, using thermal insulator obtained from agricultural waste. The work focuses mainly on the comparison of the thermal performance and the fabrication costs of two identical SWHS of the same dimensions, design, manufactured in

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the same manner, operating in the same conditions. One of the two collectors and storage tank of these SWHS uses the glass wool, and the other uses a natural vegetable fiber, coconut coir, as heat insulation. The comparison extends to other SWHS from the literature, using traditional thermal insulation.SWHS realized are of thermosiphon type. They include an innovative internal heat exchanger made of rolled copper tube placed diagonally in the storage tank.

Table 1
Chemical components of coconut fiber and coconut pith

Chemical component	Results (%)		
	Coconut fiber	Coconut pith	Test method
Lignin	36.73	45.12	TAPPI-T222-cm-98
Holocellulose	67.63	58.82	Acid chlorite's Browing
Cellulose	51.12	48.21	TAPPI-T203-cm-93

2. Materials and Methods

2.1. Determination of the thermal conductivity of the coconut fiber (origin Côte d'Ivoire)

Coconut husk which is the principal source for the coir fibers was collected from locally available waste bunch of the coconut fruit. Raw coconut fruits were obtained from a coconut plantation in the city of Yamoussoukro situated in the center of Côte d'Ivoire. Fibers were extracted from the external layer of the exocarp and from the endocarp of the fruit.

2.2 Experimental procedure

The sample with a cross section of 200 mm x 210 mm and a thickness of 40 mm had a mass of 37 g and volume mass 22 kg/m^3. Coconut husk is rich in cellulose and lignin, which are the two major compositions for producing binderless fiberboard (Panyakaew and Fotios, 2011).The chemical components of coconut husk (fiber and pith) are shown in Table 1 and these were measured according to the procedures in Technical Association of Pulp and Paper Industry (TAPPI) standard. The coconut fibers were firstly pulled out from the husk. Practically, husks were soaked in water to ease the extraction of the fibers. The extracted fibers were washed again to remove the embedded dirt between the fibers. Finally, the fibers were dried at ambient temperature for 48 h. Each single fiber was carefully picked.

2.3 Thermal conductivity test

The thermal conductivity of all fiberboards was measured at room temperature and normal pressure using the steady-state bi-substrate technique, a well-established approach for bulk material. The apparatus is indicated in Figure 1. In its basics, this apparatus is a box one side open, in which heat is generated by means of an electric heating system. The walls of the box are thermally isolated with a ceramic fiber material. This is a primary apparatus that uses steady state conduction heat transfer as principle and allows determining thermal conductivity. The basic principle of operation is to create one dimensional axial heat flow through the sample in order to use the Fourier equation of heat conduction (Zhou *et al.*, 2010):

$$q = -k_{ins} A \frac{dT}{dx} \tag{1}$$

where q is the steady-state flow, k_{ins} is thermal conductivity, A is the cross-sectional area of the sample, and dT/dx is the temperature gradient.

For thermal conductivity determination, panel walls were mounted on the open side and closing the box completely. A constant heat flow was supplied to the sample through a controlled power supply. The method consisted of establishing a one-way heat flux, normal to the surface of the sample to be tested, as presented in Figure 1. The sample was placed between a hot source and a cold one. The material tested is very heterogeneous. So, temperature measurements reported in this study were carried out using a total of nine small locally designed thermocouples. These thermocouples were fixed using an adhesive tape and the contact with the sample is optimized thanks to silicone grease. Four thermocouples located in the hot face, four in the cold face and one introduced at the centre of the sample. Temperatures were measured once every 10 minutes while 10 hours. The variation in temperature generates a heat flux proportional to the temperature difference. Once steady state is reached, one can record the average temperature on the cold and hot sides of the sample. The air temperature of the hot box and that of ambient air were also measured. Knowing the power delivered by the hot source, it then becomes possible to calculate the thermal conductivity of the material by reporting the values obtained in the Fourier equation.

2.4 Solar water heaters system

Each one of the SWHS realized includes a solar collector of a 2 m^2, heat exchanger arranged in diagonal in the storage tank, a storage whose capacity is 95 liters and the piping of connections as shown in Figure 2.

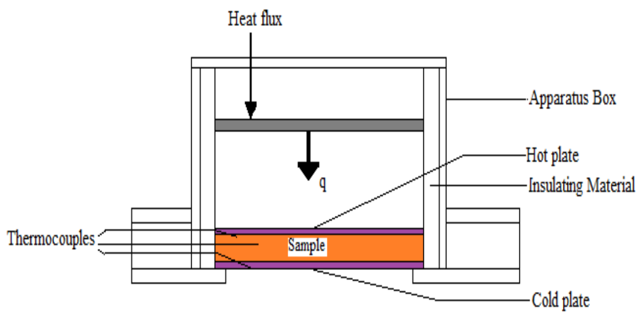

Fig. 1 Experimental configuration of the thermal conductivity test.

Fig. 2 Pictures showing one SWHS and the thermal insulation of one of them with the coconut fiber

With an outside diameter of 12 mm and a length of 6 m, the surface of the heat exchanger is 0.226 m^2. One of the systems has a glass wool insulation of thermal conductivity 0.040 W.m^{-1}.K^{-1} when the other one is isolated with a local vegetable fiber (coconut coir). The thickness of the heat insulator used in the solar system is the same in the solar collector and in the storage tank for the two SWHS. The solar collector includes an absorber composed of 12 tubes separated from 12 mm and painted in matt black. Below these tubes, is a leaf of aluminum which reflects the thermal radiation received towards the absorber.

During the experimental period, the measure of total radiation received by the solar collector, and that of the temperature in various points of the system were carried out. The total radiation is measured by means of a KIPP and ZONEN pyranometer which relative uncertainties of ± 2%. It is connected to a digital integrator, of the same mark, allowing the reading of the immediate received solar energy and the irradiation. The pyranometer is horizontally placed to get all the solar radiation. A data acquisition card, made, by our care, allows recording the temperature in diverse places of the system. To avoid perturbing the fluid flow, one uses probes of small dimensions made of 1.6 mm diameter of diode 1N4148 in silicon, ± 0.5°C precision. Before using, the probes are calibrated using a digital thermometer which gives coefficients of conversion temperature/tension completely identical with a margin of 0.1. The center of measure was already made in earlier publications (Koffi *et al.,* 2014). The evaluation of the thermal loss coefficients is the fundamental task to assess the flat plate solar collectors' performance. Thermal analysis of solar collectors is covered in many solar thermal engineering texts were also already made in earlier publications (Koffi *et al.,* 2014). The experimental mass flow rate is obtained by calculation from the establishment of the heat and mass transfer balance between the inlet and outlet collector hot fluid according to the relation (Koffi *et al.,* 2014):

$$\dot{m} = \frac{I(\tau\alpha)A_c}{C_p\left(T_{f2} - T_{f1}\right)}\left[F^{'}(\tau\alpha) - F^{'}U_L\left(\frac{T_m - T_a}{I_T}\right)\right] \tag{2}$$

Where $T_m = \frac{1}{2}\left(T_{f1} + T_{f2}\right)$

At each experimental run, the efficiency of the collector was calculated from (Koffi *et al.,* 2014):

$$\eta = \frac{Q_u}{A_c I} = F^{'}(\tau\alpha) - F^{'}U_L\left(\frac{T_m - T_a}{I}\right) \tag{3}$$

The concept of the heat exchanger effectiveness, ε_{hx}, has been introduced by Nusselt to compute directly the rate of heat transfer from the inlet temperatures of the fluids (Kreith, 1976). An evaluation of the heat exchanger effectiveness was made with the following equation (Haltiwanger and Davidson, 2009):

$$\varepsilon_{hx} = \frac{T_{f3} - T_{f4}}{T_{f3} - \bar{T}_w} \tag{4}$$

This parameter reduces the useful heat delivered by the solar collectors and is therefore desirable to be close to unity. The mean daily efficiency (η_d) of a solar water heater is an important parameter which describes the thermal performance of the system, and a value with comparative constancy. The mean daily efficiency (η_d) can be calculated as follows (Huang *et al.,* 2010):

$$\eta_d = \frac{MC_p\left(T_i - T_f\right)}{A_c.H} \tag{5}$$

The possible errors in the determination of the mass flow rate, the efficiency, collector efficiency factor, collector heat removal factor and overall heat loss coefficient and temperature fluctuations due to instrumentation error, has already been estimated (Koffi *et al.,* 2014).

The uncertainties in the various variables used in the determination of the collector efficiency, mass flow rate, for collector heat removal factor and for overall heat loss coefficient are: 0.1°C for any temperature measurements, 2% for solar irradiance and 0.001 m for any distance measurements. Following the procedure of Holman and Gajda (1989), the uncertainty of the collector efficiency was estimated to be within 6.5%, 5% for the efficiency, 1.15% for collector heat removal factor and 0.12% for overall heat loss coefficient.

3. Results and discussion

3.1 Thermal conductivity of coconut fiber

The thermal conductivity of coconut fiber obtained after 10 h of maintaining the device in a steady state is k_{ins} = 0.074 W/m K, with a result precision of ±5%. This value extends from 0.0703 to 0.0777 W/m K which is in good agreement with that found in the literature (Manohar *et al.*, 2006).

Table 2 compares the thermal conductivity of coconut fiber found and other common thermal insulation materials. It is evident that the thermal conductivity of coconut fiber is in the same range of particleboard from mixture of durian peel and coconut coir, cotton stalk fiberboard and vermiculite and slightly higher than that of other fibrous materials and cellular materials, such as fiberglass, rockwool and extruded polystyrene (Al-Homoud, 2005). Note that materials with the thermal conductivity less than 0.25 W/ (m·K) are generally seen as thermal insulations (Al-Homoud, 2005). Therefore, it can be concluded that coconut fiber is a good insulating materials.

3.2 Performance of the solar water heaters

Performance and testing of a hot water withdrawal was carried out in Yamoussoukro, the capital of Côte d'Ivoire, situated in Sub-Saharian Africa between 5° and 11° north latitude.

According to Kalogirou (2009), to achieve a good annual performance of a solar collector, the tilted angle shall be equal to the latitude of the location plus 5°. As the latitude of Yamoussoukro is 6.58°N, the thermal collector array was set at a tilted angle of 10°N to the horizontal ground and oriented to the South. The annual solar energy received in this area lies between 1650 and 1950 kWh/m². Côte d'Ivoire lies within a tropical region and hence experience tropical climate. The country has two main distinct seasons: the rainy season (from March to August) and the dry season (from November to March). The other months are the boundaries of the two seasons. The temperatures throughout the year respectively range from a minimum average of 22°C to a maximum average of 32 °C.

The two solar water heaters was installed and tested under the actual field conditions of Yamoussoukro, Côte d'Ivoire. The experiments were performed at different meteorological from October 2018 to September 2019. Performance and testing of a hot water withdrawal was carried out in Yamoussoukro and throughout a sunny day. The daily irradiation of sunny chosen is 5033Wh/m²/day. During the experimental period, measurements of the basic physical parameters that govern natural circulation by thermosiphon, total irradiation received by the collector, total daily irradiation, temperatures in various points of the system (connection piping, inlet and outlet of the hot fluid in the collector and in the heat exchanger) are reported with the aim of determining the mass flow rate and the thermal performances of this system.

Figure 3 shows the variation of difference across collector, ambient and mean plate temperatures for the two types of collector with local time for a selected sunny day. During the test period, the minimum recorded ambient temperature was 20.3°C and the maximum recorded ambient temperature was 39.4°C at 3:40 p.m. As expected, the fluid temperature difference across the collector for the two systems follows the same trend. The difference of fluid temperature across the collector increase during the morning hours to reach a maximum about 35°C and 30°C at 1:00p.m. respectively for the system using glass wool as thermal insulator and for the system using coconut fiber as thermal insulator and then, start decreasing in the afternoon. These results are better than those of Ma *et al.* (2011).

Table 2
Thermal conductivity of various materials.

Materials	Density (kg/m³)	Thermal conductivity (W/mK)	Reference
Coconut fiber	22	0.0703-0.0777	Present work
Cotton stalk fiberboard	150–450	0.0585–0.0815	Zhou et al. (2010)
Low-density wheat straw board	150–250	0.0481–0.0521	Zhou et al. (2004)
Particleboard from mixture of durian peel and coconut coir	311–611	0.0728–0.1117	Khedari et al. (2004)
Kenaf binder less board	150–200	0.051–0.058	Xu et al. (2004)
Wood (pine, lauan)	450–630	0.151	Xu et al. (2004)
Fiberglass	24–120	0.034–0.047	Zou (2008)
Rockwool	80–200	0.025–0.035	Zou (2008)
Extruded polystyrene	24–42	0.026–0.035	Zou (2008)
Polystyrene (closed cell foam)	16–35	0.034–0.038	Zou (2008)
Expanded perlite	78–224	0.0477–0.0616	Zou (2008)
Vermiculite	80–200	0.047–0.07	Zou (2008)

During the day time, the difference of temperature across the collector in the two systems is at first negative. The bait of the operating of the thermosiphon takes place when this difference of temperature becomes positive (Mertol *et al.,* 1981), indicating energy transfer from the collector to heat exchanger which it is transferred then to the storage tank. At the end of the day and during the night, the increase in water temperature across the collector is negative, indicating energy transfer from the storage tank to heat exchanger, which is characteristic of the reverse flow. It is to be noted that the maximum mean plate temperature reached 71.5°C and 64°C at 2:20pm respectively for the system using glass wool as thermal insulator and for the system using coconut fiber as thermal insulator. These results are in perfect concordance with those of Mertol *et al.* (1981), those of Sakhrieh and Al-Ghandoor (2013).

Figure 4 presents the heat flux received by solar collector and the useful energy gain for the two SWHS according to the time. The two SWHS have the same dimensions and are submitted to the same weather conditions. So, they have the same behavior in the face of heat flux. We notice that the heat flux and the useful energy gain evolve according to time. The heat flux and the useful energy gain reach their peak at 12:30 am and then begin decreasing. The reached maximal values are of 1215 W/m^2 for heat flux and 921 W/m^2 for useful energy gain.

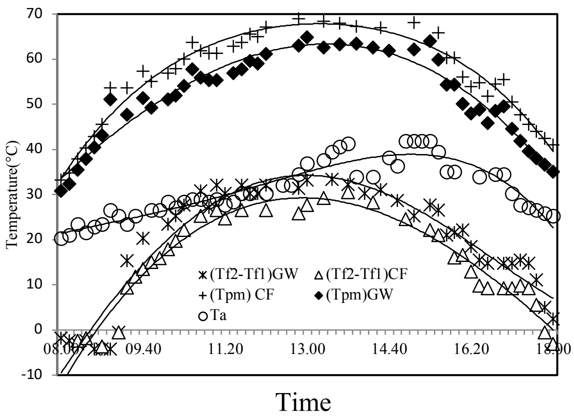

Fig. 3 Time variation of difference across collector, ambient and mean plate temperatures for the two types of collector.

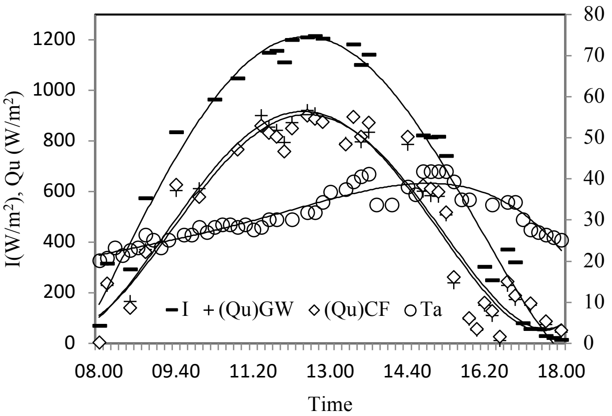

Fig. 4 Time variation of radiation intensity, useful energy gain, and ambient temperatures for the two types of collector.

Table 3 recapitulates a quantitative comparison between our results to numerical and experimental ones, for different types of heat insulations (polyurethane, polystyrene, armaflex, glass wool, glass fiber). It includes six columns among which three last ones represent respectively the ambient temperature, the outlet temperature of solar collector and the last column presents the difference between this temperature and the ambient temperature, and it to make a comparison. The results obtained with the coconut fiber as thermal insulator are comparable to those of other present authors.

We note an increase of inlet exchanger temperature for both systems which reach their maximal values respectively at 2:20 pm then decrease with the falling of the sun as shown in Figure 5. The maximal value of 72°C is reached for the SWHS which uses glass wool as thermal insulator when it is 66°C for the SWHS which uses coconut fiber as thermal insulator. For the SWHS which uses glass wool and the SWHS which uses glass wood as thermal insulator, the difference between the exchanger inlet water temperature and the ambient temperature is respectively 32.6°C and 26.6°C, when it is 23 °C at these same points in the work of Hussein (2002) and 7.5-18.8°C in those of Balotaki and Saidi (2017).It is noted, moreover, that the outlet temperature in the storage tank goes up regularly to reach a maximum value of respectively 57.2°C and 52.5°C at4:00 pm for the SWHS using glass wool as thermal insulator and for the SWHS using coconut fiber as thermal insulator. These results are in perfect concordance with those of Tse and Chow (2015) which studied an indirect thermosyphon solar water heating system with heat exchange coil. They use respectively fiber glass as insulating material in the solar collector and polyurethane in the water tank.

Figure 6 presents the time variation of instantaneous efficiency and mass flow rate for the two types of SWHS. The mass flow rate increase gradually with heat flux to reach its maximum in the middle of the day and then decrease with the falling of the sun to reach their minima in the night. The mass flow rate is found to reach a maximum respectively at 12.30 a.m. and 12.00 a.m. for the SWHS using glass wool as thermal insulator and for the SWHS using coconut fiber as thermal insulator. This maximum value is 0.0098 kg/s for the first system and 0.0078 kg/s for the second one. These results are better than some data in the literature (Tse and Chow, 2015). The collector efficiency followed the same trend as the heat flux and useful energy. It increases until noon time and then decreases as shown in Figure 6. The collector efficiency shows a proportional relationship with the mass flow rate (Mandal and Ghosh, 2020; Yassen *et al.,* 2019). When the mass flow rate increases, the collector efficiency rises to owe to heat flux, taking more heat energy (Balaji *et al.,* 2019). The maximum efficiencies occur respectively at 1:10 pm true solar time for the two systems. The maximum efficiencies values are respectively 65.30% (with glass wool) and 58.7% (with coconut fiber). Our results are in agreement of Hang *et al.* (2012) and Ge *et al.* (2012) and better than those of Mandal and Ghosh (2020).

The top and overall loss coefficients are shown in Figure 7. For the two SWHS realized, the increase in top and overall loss coefficients was found to follow that of the mean plate temperature. The collector overall heat loss coefficient has a value range of 4.26 – 6.70 (an average of 5.60 W/m^2°C) for the SWHS using glass wool as thermal insulator and of 4.84 – 8.31 (an average of 6.97 W/m² °C) for the SWHS using coconut fiber as thermal insulator. These averages of overall heat loss coefficient values are in good agreement with those of Dagdougui *et al.* (2011).

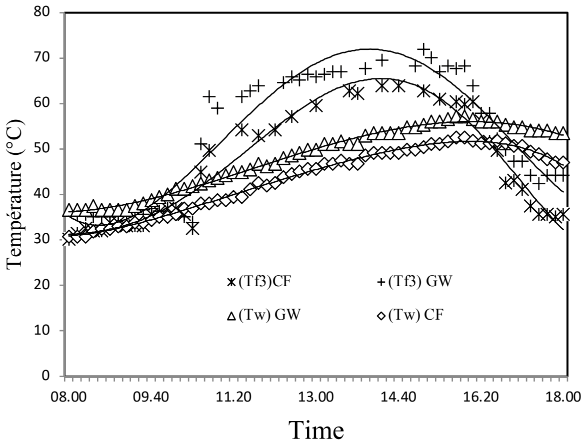

Fig. 5 Time variation of Inlet exchanger temperature, Outlet tank temperature for the two types of SWHS

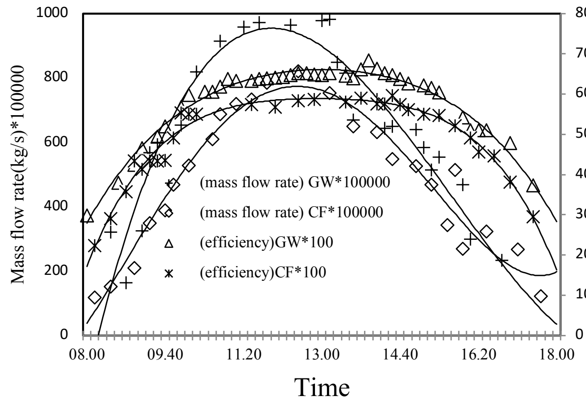

Fig. 6 Time variation of instantaneous efficiency and mass flow rate for the two types of SWHS

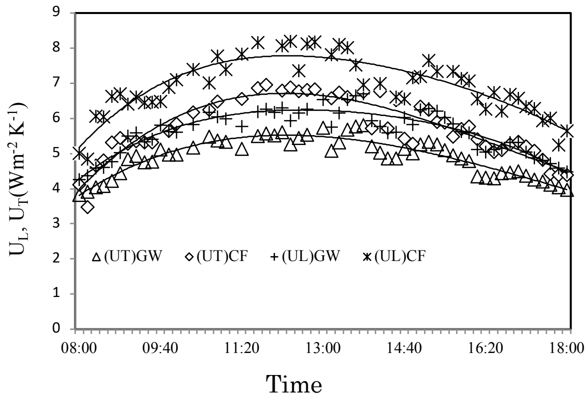

Fig. 7 Time variation of top and overall loss coefficients for the two types of collector

Table 3
Maximum experimental values recorded from Figures 4 and 5.

Study cite	Type of insulation(thickness)	Heat flux max (W/m²)	T_{amb} (°C)	T_{f2} (°C)	$\Delta T = T_{f2} - T_{amb}$
Present study(CF)	Coconut fiber (50mm)	1215	39.4	80	40.6
Present study(GW)	Glass wool (50mm)	1215	39.4	83	43.6
Sakhried and Al-Ghandoor (2013)	Polyurethane (50mm)	1004.33	26	76	50
Ayompe and Duffy (2011)	Armaflex (22mm)	917.2	22	70.3	48.3
Ma et al. (2011)	Glass fiber (20mm)	800	33	65	32
Khalifa and Jabbar (2010)	polystyrene (40mm)	840	20	57	37
Esen and Esen (2005)	Glass wool (100mm)	1000	28	70	42
Abdullah et al. (2003)	Polystyrene(15mm) and glass wool(25mm)	880	42	61	19

Table 4
Efficiency equation and collector principal physical characteristics

Type of insulation	Efficiency equation	F' (τα)	F'	F'U_L	U_L (W/m²K)
Coconut fiber	$\eta = 0.79 - 5.86(T_m - T_a)/I_T$	0.79	0.94	5.86	6.23
Glass wool	$\eta = 0.80 - 5.26(T_m - T_a)/I_T$	0.80	0.96	5.26	5.51

Table 5
Different results of mean daily efficiency for a sunny day

Systems	Flat-plate system without a heat exchanger (Duffie and Beckman, 2006)	Flat-plate system with a mantle heat exchanger (Haltiwanger and Davidson, 2006)	Our study (with glass wool)	Our study (with coconut fiber)	All-glass evacuated tubular system (Haltiwanger and Davidson, 2006)
Mean daily efficiency (%)	57	50.28	54.80	41.10	48.16

By using a curve fitting technique, it could be found via Figure 8 that the instantaneous efficiency of the collector could be represented as a linear relation of the measuring parameter $(T_m - T_a)/I$. The intercept of the efficiency line shown in Figure 8 with the y-axis represent the product $F'(\tau\alpha)$, while the slope of the efficiency line represents $F'U_L$. The values of $F'(\tau\alpha)$, and $F'U_L$ are summarized in Table 4. This shows undeniable qualities of insulation of this material that one can now take account in the insulation of thermal solar collectors as well in the design of heating waters as in that solar driers; because, according to Duffie and Beckman (2006) for a good collector, the pairs of values of the intercept $F'(\tau\alpha)$, and the slope $F'U_L$, of the collector efficiency curve are 0.8 and 4.5 W/m²°C.It is 0.6 and 8.5 W/m² °C, for a poor collector.The coefficient of thermal exchange of the heat exchange is estimated to be respectively 149.15 W/m²K and 151.8 W/m².K for the system using glass wool as thermal insulator and for the system using coconut fiber as thermal insulator. These results are in agreement with those found in the literature.

According to Wellinger and Messungen (1982), the transfer of heat taking place by natural convection, the coefficient of transfer is of the order of 150 W/ m²K.Figure 9 shows the variation of the heat exchanger effectiveness with solar time for the two systems. For a major part of the period of heat input to tank on the day of measure, from 08:40 am to 4:40 pm., the effectiveness was found was found to be between 40% and 96% for the system using glass wool as thermal insulator and 35% and 86% for the system using coconut fiber as thermal insulator as shown in Figure 9.

The average daily heat exchanger effectiveness obtained is 80.53% for the first system (with glass wool) and 73.37% for the second one (with coconut fiber). These results are interesting compared to some values in the literature. Haltiwanger and Davidson (2009), which also used in their works an immersed coiled heat exchanger, showed after one hour of measure that the efficiency of the used heat exchanger is understood between 61 % and 68 % with an average of 65.1 %.

The mean daily efficiency (η_d) of a solar water studied are respectively 54.80% (with glass wool) and 41.1% (with coconut fiber). Table 5 compare this value to those obtained in the literature by other authors concerning the systems with collectors made of a selective surface absorber and have similar dimensions as ours, for a sunny day. Experimental results show that the mean daily efficiency of ours SWHS is acceptable by comparing them to those of the other authors.

3.3. Economical study

At the economic level, the vegetable fibers are much less expensive than the synthetic fibers. By referring to table 6, we notice that compared with the synthetic fibers and with the other vegetable fibers, coconut fiber presents one of the lowest prices per kilogram. This remark is confirmed by making economic comparative study between the both solar systems realized. All material used for the realization of both SWHS as well as their respective prices are presented by Table 6.

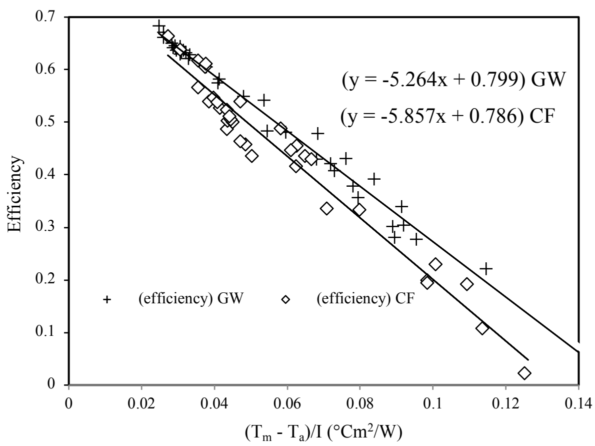

Fig 8. Comparative efficiency of the two types of collectors with $(T_m - T_a)/I$

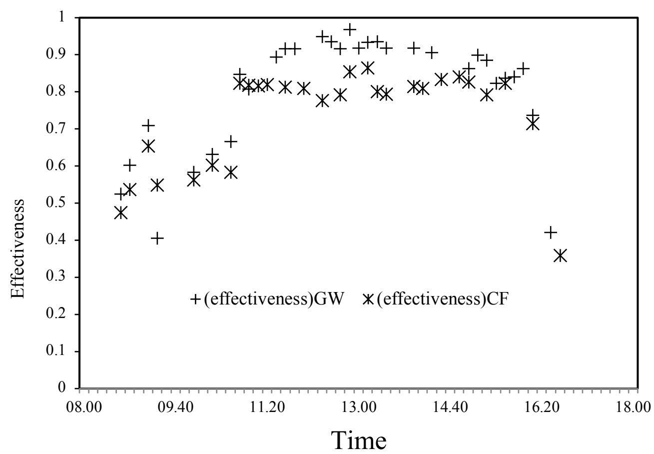

Fig. 9 Heat exchanger effectiveness of the two SWHS versus the time of day

Table 6
The cost of materials used for the manufacture of the two types of collectors including tanks and labor, in US dollars (US$)

Quantity	Part	Cost (US$) glass wool	Cost (US$) coconut fiber
4	Galvanized steel tubes of 0.5-in. diameter and 6 m long (standard length)	129	129
1	Galvanized steel tube of 1-in. diameter and 6 m long	19	19
3	Galvanized steel sheet (2×1 m standard dimensions) 1 mm thick	94	94
3	Galvanized steel sheet (2×1 m) 2 mm thick	194	194
1	Aluminium foil (2.5×1.5 m)	2.4	2.4
1	Roll of glass wool, or coconut coir, 0.2 m^3 (standard dimension) (50 mm thickness)	220	17
1	Glass plate of 4 mm thick (2.2×1 m)	84	84
1	Tin (5 kg) of non-glossy black paint +painting brush+ thinner	20.7	20.7
1	Tin of silicone	18	18
1	Bag of Steel rivets	7.5	7.5
1	10 m flexible plastic hose and clips (for the piping)	19.5	19.5
	Labor cost	50	50
	Total	**858.1**	**655.1**

The price of realization of the solar water heater using glass wool as heat insulator is 858.1 US dollars when for the system using the coconut matting as heat insulator the price of realization is 655.1US dollars. The comparison of the prices of both types of SWHS shows that the system using coconut fiber is cheaper than which using glass wool. The price of the glass wool represents 25.64 % of the total cost of the SWHS while that of the coconut fiber represents only 2.60%. Therefore, using coconut fiber as a heat insulator is more economic than of the glass wool one. It would thus be very interesting to turn to this type of thermal insulator, locally available and cheap.

4. Conclusion

The work presented in this paper is limited to measure thermal conductivity of coconut fiber and compare the performance of two thermosiphon SWHS with an internal heat exchanger different due to the insulation has been fabricated from locally available materials and tested under real climatic conditions. The one using glass wool and the other coconut fiber as thermal insulator. Experimental thermal conductivity was in good agreement with those found in the literature. Significant results were obtained when the coconut fiber is used in solar water heater as a thermal insulator.

The experimental results of the performance test presented above show that the system reaches efficiency and a water temperatures at the outlet of the solar collector respectively of 65.30% and of 83°C for the SWHS using glass wool as thermal insulator and of 58.7% and 58°C for the other one. The maximum water temperature in the storage tank reached 57.2°C with a thermosiphonic mass flow rate of 0.0098 kg/s for the SWHS using glass wool as thermal insulator and 52.5°C with a thermosyphonic mass flow rate of 0.0078 kg/s for the SWHS using coconut fiber as thermal insulator. The average daily heat exchanger effectiveness obtained is 80.53% for the first system(with glass wool) and 73.37% for the second one (with coconut fiber) when the mean daily efficiency of the two SWHS studied are respectively 54.80% (with glass wool) and 41.1% (with coconut fiber).

From the results of this study, one can say that the coconut fiber is an ecologically friendly, an economically viable and sustainable alternative to be used as thermal insulator in hot tropical weather. It can be said that the results of this study are original and important when compared with those of previous works.

Nomenclature

A_c	collector area (m^2)
A_e	outside heat exchanger heat transfer area (m^2)
CF	coconut fiber
D	outer diameter of riser tube (m)
e	thickness of the sample (m)
F'	collector efficiency factor
F_R	collector heat removal factor
GW	glass wool
k_{INS}	thermal conductivity of the insulation (W/mK)
L_{INS}	thickness of insulation (m)
$\dot{m}$	mass flow rate (kg/s)
Q_u	useful energy (W/m^2)
T_a	ambient temperature (°C)
T_e	temperature of cold water network entering in storage tank (°C)
T_f	average water temperature in storage tank at end of test (°C)
T_{f1}	inlet working fluid temperature (°C)
T_{f2}	outlet working fluid temperature (°C)
T_{f3}	working fluid temperature at inlet of heat exchanger (°C)
T_{f4}	working fluid temperature at outlet of heat exchanger (°C)
T_i	average water temperature in storage tank at start of test (°C)
T_w	temperature of hot water at the exit of storage tank (°C)
T_{pm}	mean absorber plate temperature (°C)
U_e	thermal coefficient exchange of heat exchanger (W/m^2K)
U_L	overall loss coefficient (W/m^2K)
U_t	top loss coefficient (W/m^2K)

Greek letters

ΔT_m	log-mean temperature difference (K)
ε_{hx}	heat exchanger effectiveness
ε_p	emittance of plate surface
ε_c	emittance of glass cover
σ	Stefan-Boltzmann constant (W/m^2K^4)
$(\tau\alpha)$	fraction of the solar radiation absorbed
η	collector instantaneous efficiency (%)
η_d	mean daily efficiency (%)

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