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EXPERIMENTAL THERMAL PERFORMANCE STUDY ON A THERMOSYPHON SOLAR WATER HEATER, WITH AN INTERNAL EXCHANGER, IN CÔTE D'IVOIRE

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ABSTRACT

A thermosyphon solar water heater made from available materials has been achieved locally. Its thermal performance is analyzed experimentally, using several sunny and cloudy days data, to demonstrate its viability in Côte d'Ivoire. The first results give a 50% average efficiency, with storage tank temperature above 55°C. These results show that the system is suitable for application in Côte d'Ivoire weather conditions. All those performances, combined with manufacturing simplicity and the absence of moving parts, make the system an interesting technological solution. The results can then be used for the dissemination of the system.

KEYWORDS: Solar Water Heater, thermosyphon, useful energy, thermal performances, efficiency

Nomenclature

E_u	Useful energy gain (W/m^2)	η	Collector efficiency (%)
A_c	Absorber area (m^2)	K_c	Overall heat loss coefficient (W.m^{-2}.K^{-1})
I_c	Absorber global insolation (W/m^2)	T_a	Ambient temperature (°C)
C_p	Specific heat of the working fluid (J.kg^{-1}.K^{-1})	T_p	Average absorber plate temperature (°C)
$\dot{m}$	Fluid flow rate (kg/s)	T_s	Outlet tank temperature (°C)
F_p	Heat removal factor	T_1	Inlet collector temperature (°C)
τ	Transmittance of glazing	T_2	Outlet collector temperature (°C)
α	Collector plate absorbance		

INTRODUCTION

In Côte d'Ivoire, water is heated using mainly three energy sources: biomass (wood and charcoal), electricity and natural gas (butane). Very few solar water heaters are used. The use of the Solar Water Heaters (SWHs) is interesting with regard to energy saving in the modern residential areas, as well as in certain commercial sectors. Indeed, such systems can, in certain cases yield 50% energy saving. In Côte d'Ivoire, the sun shines between five and eight hours per day. That gives an annual average solar insolation of about 5.0 kWh/m²/day, with a peak of sunshine between March and April, according to the regions (Tiéné, 2004). It is then interesting to encourage the use of the SWHs in Côte d'Ivoire.

A previous comparative study between SWHs energy and classical sources of domestic hot water productions has been carried out (Sako, 2002). This study shows that SWHs could be more competitive if the purchase price was reduced.

In order to strengthen local technical capacity, to accelerate dissemination and ensure the appropriation of SWHs technology as well as to stimulate the acceptance of other solar technologies in Côte d' Ivoire, we propose an innovative design of thermosyphon SWH, using readily available materials in order to reduce costs.

This paper aims to outline the results of the experimental thermal performance test of the system, carried out locally (in Yamoussoukro, 6.54°N of latitude), in order to demonstrate its applicability, so as to encourage its wide use in the country.

Experimental set up and test procedure

The most commonly used SWHs for domestic needs is the natural circulation type. A large number of experiments have been carried out around the world to predict the performances of such a system (Joudi, 1999; Kalogivu, 1999; Karaghouli, 2001; Nahar, 1995). These studies show a difference in performance due to different designs, manufacturing materials and weather conditions.

Experimental set up

The experimental system is manufactured in the Mechanical and Energetic Engineering Department, based in Institut National Polytechnique Félix Houphouët Boigny.

The main parts of the system are the collector and the hot water storage tank, as shown in Fig. 1.

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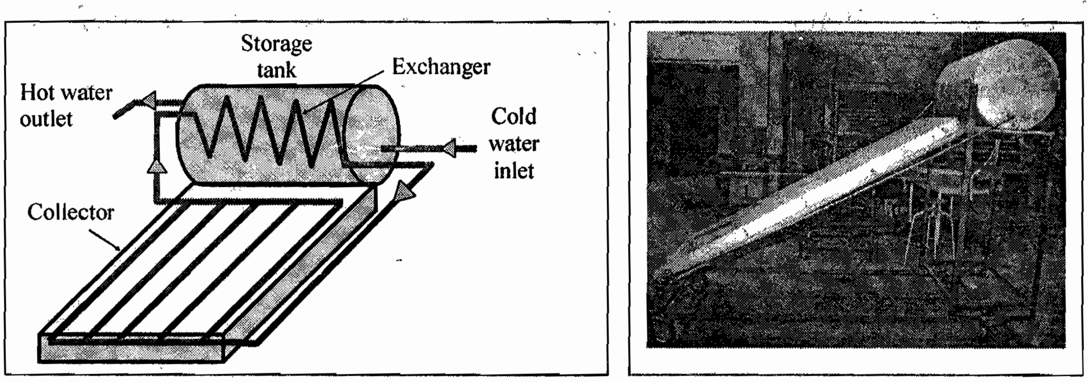

Figure 1: The natural circulation type solar water heater

The system consists of a 2 m^2 flat plate collector, with a 10° angle from the horizontal, so as to receive the maximum solar radiation, a thermally insulated horizontal storage tank of 95 litres and interconnecting piping. The black painted tubing grid is spaced at 60mm with 12mm external diameter pipes brazed to 24mm diameter copper tube manifolds. A 5cm thick glass-wool (thermal conductivity: 0.04 W.m^{-1}.K^{-1}) is used to insulate the casing. It is placed on the back pan and around the sides. An aluminium foil is attached to the insulation to reflect the emitted heat radiation back to the absorber. The collector cover is made of 4mm glass plate, which is attached to a galvanized steel frame.

The thermosyphon system relies on the natural convection of hot water rising from the collector to carry the heat up to the storage tank. When the heat of the collector is transferred to the water, that water becomes less dense than the one in the storage tank. Hot water is pushed through the collector and enters the top of the hot water storage tank at higher temperature and cold water from the tank simultaneously descends to the bottom of the collector.

Test procedure

The measurements relate mainly to the global insolation and the collector temperatures in 16 points (Fig.2), and also to the storage tank and the connecting piping temperatures.

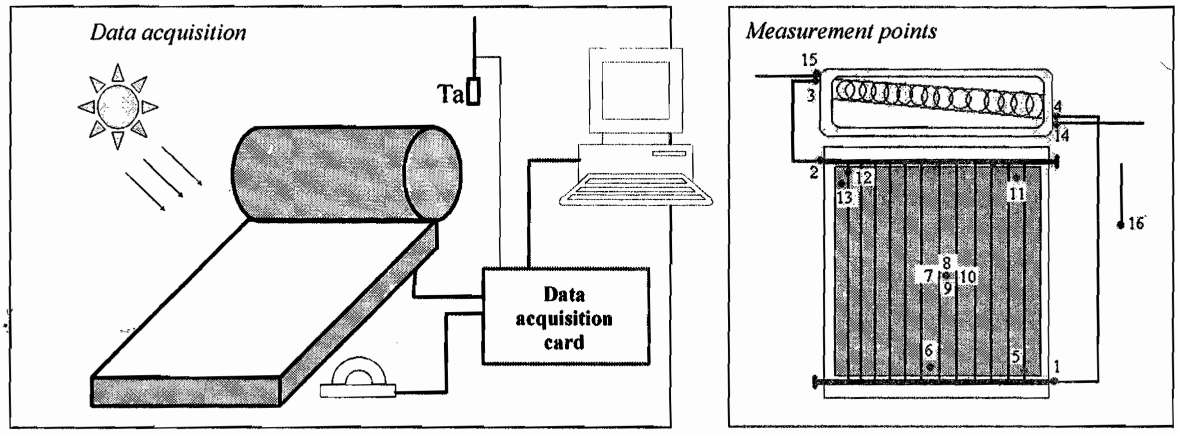

Figure 2: System schematic diagram and measurement points position

The total incident solar radiation on the collector plane is measured using a Kipp and Zonen CM 10 pyranometer. It is connected to a numerical integrator, allowing the reading of instantaneous power and energy received, by digital display, over a given period. The pyranometer is placed in an horizontal position to receive the whole solar radiation. The relative error on the measures is ± 2%.

To avoid perturbing fluid flow, probes of low dimensions made of diode 1N4148 with silicon of 1.6mm diameter, of ± 0.5°C precision, are used. All the probes used for measurements are calibrated. The probes are mounted as shown in Fig. 2.

Data are collected for several sunny and cloudy days. The storage tank remains filled during the day.

RESULTS AND DISCUSSION

The thermal performance of a flat plate solar collector may be expressed in the form of a linear performance characteristic, relating the rate of useful heat output per unit aperture area (E_u), the solar radiation input (Ic) and the heat losses (K_c).

$$E_u = I_c A_c(\tau\alpha) - K_c A_c(T_p - T_a) \qquad (1)$$

The instantaneous efficient η of the collector is defined as the ratio of useful heat gain (E_u) delivered per unit area to the solar radiation intensity (Ic).

$$\eta = \frac{E_u}{A_c I_c} \qquad (2)$$

The collector's instantaneous efficiency is influenced by several factors such as: the used materials, the absorber design, the glass properties, the weather and the operating conditions. According to Karaghouli and Alnasser (Karaghouli, 2001):

$$E_u = F_p[I_c A_c .\tau.\alpha - K_c A_c (T_p - T_a)] \qquad (3)$$

$$\eta = F_p.\tau.\alpha - \frac{F_p K_c (T_p - T_a)}{I_c} \qquad (4)$$

where $F_p.\tau.\alpha$ is the theoretical maximum collector efficiency.

According to Sfeir and Guarracino (Sfeir, 1981) F_p value is function of temperature T_p used in equation (4). In this study, the temperature measured is the absorber's temperature. In this case, F_p= 1.

The useful heat gained in the collector can also be obtained by measuring the fluid flow rate ($\dot{m}$):

$$E_u = \dot{m} C_p (T_2 - T_1) \qquad (5)$$

- The efficiency curve of the experimental flat plate solar collector is shown in Fig .3.

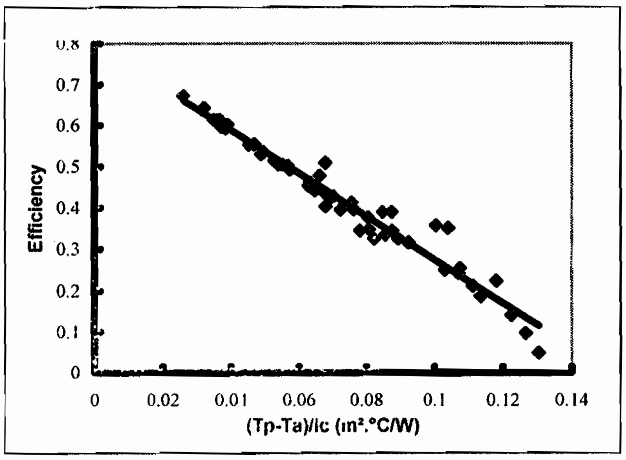

Figure 3: The instantaneous efficiency of the solar collector

As expected, the instantaneous efficiency decreases as the ratio of temperature differences to insolation increase. These results are in good agreement with those of Pierson and Javelas (Pierson, 1983), those of Karaghouli and Alnasser (Karaghouli, 2001).

The experimental data give an optical efficiency of 0.797, which is in well accordance with Sfeir works: 0.80 (Sfeir, 1981).

- For a thermal system, it is important to know the quantity of energy received and its distribution in the time. The hourly global solar radiation at the 10° angle collector from the horizontal, the inlet collector temperature, the outlet collector temperature, the ambient temperature as well as the storage tank temperature, for a cloudy day and for a sunny day, are plotted in figures 4 & 5.

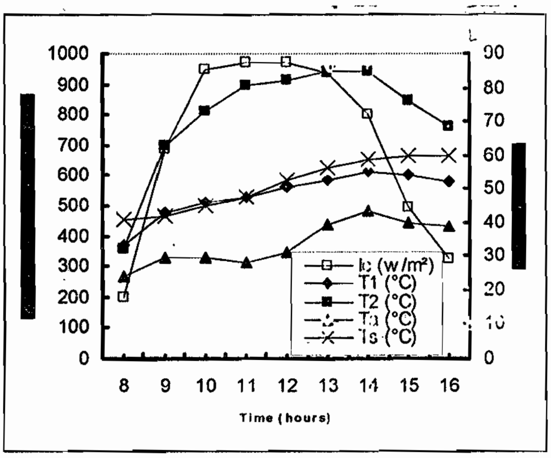

Figure 4: Hourly variation of temperatures for a sunny day

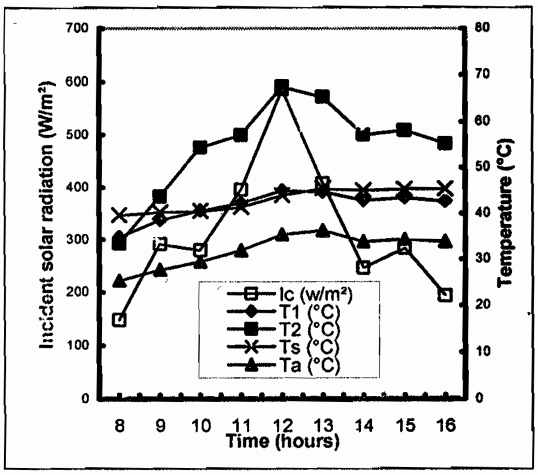

Figure 5: Hourly variation of temperatures for a cloudy day

As one can expect, the temperature values grow with the solar intensity to reach their maxima in the middle of the day; then they drop with the global insolation falling to reach their minima at night. The maximum values recorded are:

- for the sunny day : **973 W/m²** (incident solar radiation) and **60°C** (hot water in the storage tank);
- for the cloudy day: **586 W/m²** (incident solar radiation) and **45.5°C** (hot water in the storage tank).

These results show also that the temperature of the water in the storage tank is higher than that of the hot fluid at the collector outlet, at the beginning and at the end of the day, allowing a circulation in opposite direction for the thermosyphon cycle.

- From the experimental values, the useful energy and the instantaneous efficiency are plotted in figures 6, 7, 8 & 9.

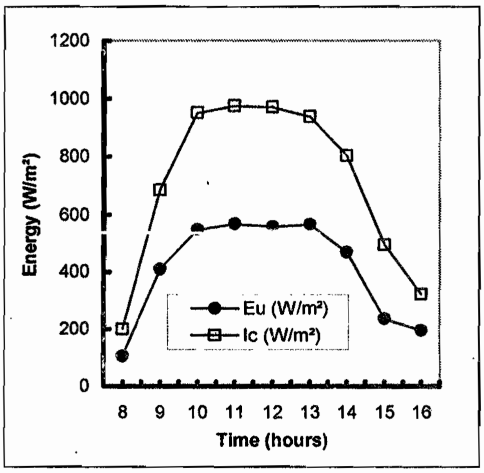

Figure 6: Hourly variations of solar radiation and useful energy for a selected sunny day

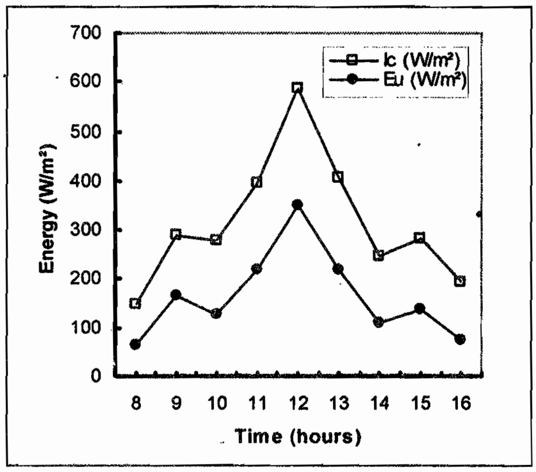

Figure 7: Hourly variations of solar radiation and useful energy for a selected cloudy day

The amount of useful energy and the incident solar radiation for the same sunny day are presented in Fig. 6. The insolation increases until it reaches its maximum (973 W/m²) at 11:00 am, then it begins to decrease. The useful energy follows the same pattern. The difference between the incident energy and the useful energy represents the collector thermal loss. The variation of the insolation and useful energy has also been done for a cloudy day (Fig.7). As shown in the figure, the insolation for that day is low and therefore the useful energy is as expected, i.e. low.

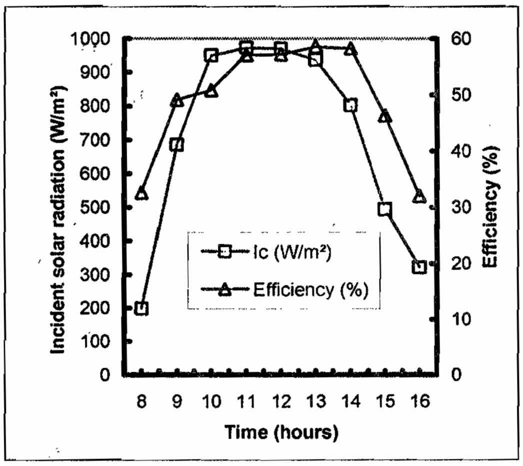

Figure 8: Hourly variations of collector efficiency and insolation for a sunny day

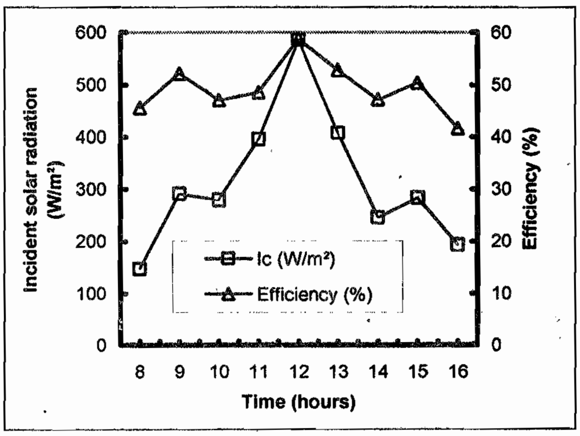

Figure 9: Hourly variations of collector efficiency and insolation for a cloudy day

The collector efficiency, which is the ratio of useful energy to solar radiation, should follow the same trend as the insolation and useful energy. It increases during the morning hours to reach a maximum of about 58.62% at around 1:00 pm for the sunny day and 58.81% at noon time for the cloudy day and then decreases. That is shown in figures 8 & 9. In spite of low useful energy, the collector efficiency is in the normal range on that day, which shows that the solar collector can capture heat at low insolation (Fig. 9).

- The experiments took place from August to January 2005. This period represents the less sunny days in Fig. 10. During this period, the collector efficiency variation is calculated for each month, as shown in Fig. 11 (Seka, 2001).

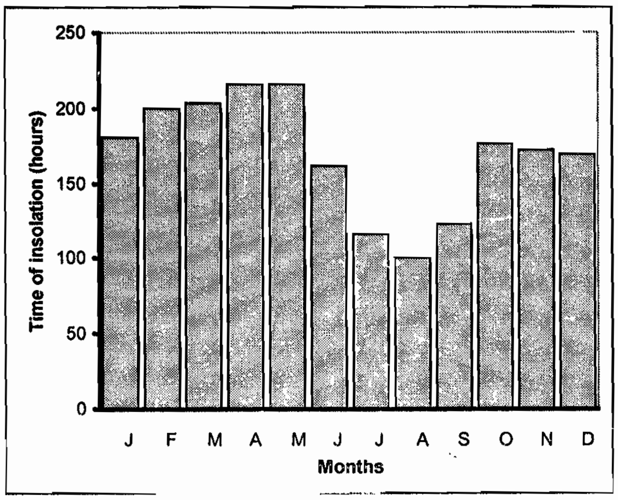

Figure 10: Insolation monthly average variation

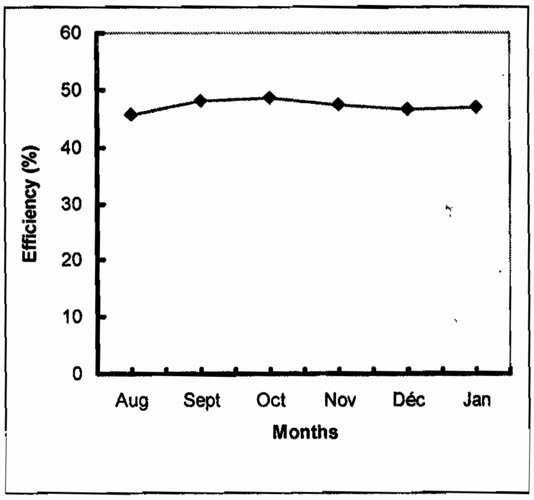

Figure 11: Efficiency monthly average variation

Fig. 11 shows that the monthly average collector efficiency varies from 45.9% to 48.6% which shows the ability of the system to convert solar energy to heat for this period. Owing to the obtained results for less sunny days, we can hope better efficiency for the other more sunny months.

CONCLUSION

The experimental results of the performance test presented above show that the system reaches an efficiency of 50%, with hot water average temperature above 55°C. These results prove that the system is suitable under the weather conditions in Côte d'Ivoire. These performances added to the relative simplicity of the system manufacturing and the absence of moving parts, make it an interesting technological solution. The study will be continued, using coconut fibre as insulating material in order to reduce the cost of the system. Tests have already been done for coconut thermal conductivity (0.074 $W.m^{-1}.K^{-1}$). An economic study is also needed to support these results.

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