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Study of the construction and testing of a storage collector-type solar water heater at Julius Nyerere University in Kankan, Guinea

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Abstract

A solar water heater of the storage collector type was produced and tested at Julius Nyerere University in Kankan during the period from January 6 to 10, 2020. The device made it possible to heat 60 liters of water per day to nearly 73 °C on average. The solar collector has an area of 1,372m^2. The device was placed in an environment of temperature varying between 22 °C and 31 °C. During the experiment, the day of 01/07/2020 was the least sunny, followed 01/06/2020 (very unclear sky). The daily average temperatures of the ambient environment, at the inlet and the outlet of the sensor are (26 °C; 25 °C and 70 °C) for 07/01202 and (27 °C; 26 °C and 73 °C) for on 01/06202, which corresponds to the daily returns 41% and 42% respectively. The days of 08 and 09/01/2020 the sunny days were favorable (clear sky), the average daily temperatures recorded are respectively: ambient (27 °C and 26 °C), re-entry (26.2 °C and 27 °C) and the output (73 °C and 75 °C) of the sensor, with yields (42% and 43%). The day of 01/10/2020 was the sunniest (very clear sky), the different average daily temperatures are as follows: 28 °C; 27 °C and 78 °C. Today's sensor efficiency is 46%. During these five days of experimentation, the average temperatures recorded are: ambient environment (26.8 ° C), at the input (26.24 °C) and the output (73.8 °C) of the sensor, with an average efficiency by 43%. This justifies the proper functioning of the system.

Keywords: design, production, solar water heater, storage collector, solar energy

Introduction

Nowadays, most countries are interested in renewables as oil reserves start to run out not to mention the risks to the environment and the cost of a barrel of oil which keeps increasing day by day. This is why there is great motivation to move towards renewable energy sources such as biomass, sun, wind and water. Solar energy is technically, environmentally and financially advantageous energy; it secures the present life of humanity. It has been used by humans for a very long time, in different forms (lighting, cooking, drying, domestic hot water, etc.) [1]. The sizing of domestic hot water production systems (solar water heaters) plays a decisive role. Indeed, their management depends on several parameters: the user's needs in terms of quantity, the desired water temperature, local climatic conditions and the performance of the flat collector system [2].

The most important basic resource for all renewable energy potentials is solar energy. The earth receives an average power of 1.4 kW/m^2, for a surface perpendicular to the earth-sun direction. This solar flux is attenuated as it passes through the atmosphere by absorption or diffusion, depending on weather conditions and the latitude of the location at ground level [3]. The solar water heater is clearly the most developed solar tool around the world today. Solar water heaters exist in fact by the millions in Japan, Israel and the USA, by tens of thousands in France, and there are few countries where they are completely unknown [4]. A solar water heater is a device that absorbs solar radiation then transforms it into heat and heats water to store it in a tank or storage tank. These sensors can be placed lower than the storage tank [1].

Depending on the period of use, there are two categories of solar water heaters: seasonal and permanent solar water heaters. Depending on the dimensions, there are three main families of individual solar water heaters meeting the needs for domestic hot water in different modes of use, namely: the self-storage solar water heater, the compact solar water heater, the -solar water with separate elements. Also, depending on their configuration, solar water heaters can be classified into three categories: monobloc, thermosiphon and forced circulation [2, 5].

The flat collector is the heart of the solar installation (solar water heater), it is a device that is used for the production of heat from solar energy. It is generally placed on the roof but can also be installed in the eaves or in the garden. The quantity of water to be heated is dictated by the number of users which thus limits its dimensions. It contains the absorber which absorbs solar radiation and transmits heat to the heat transfer fluid passing through it. A flat collector essentially consists of a transparent cover, an absorber, an exchanger, a heat transfer fluid, thermal insulation and a box. There are three groups of collectors which are: glazed flat collectors, unglazed collectors and vacuum collectors [6].

The Republic of Guinea has a humid tropical climate with the alternation of two seasons, a dry season and a rainy season. The average daily temperature varies between 25 and 40 °C, the average daily solar radiation is 4.8 kwh.m².d^{-1} and the annual average sunshine duration is 2000 hours, with a maximum in Haute Guinea (Kankan) about 2700 hours per year. The mean annual wind speeds in Guinea are between 2 and 4 m.s^{-1}. Guinea has significant solar energy potential. Thus, as part of the development of this renewable energy potential, we proposed to design and produce an experimental prototype of a storage collector type solar water heater at Julius Nyerere University in Kankan.

Material and Method

Material

Presentation of the study area

Located in the east of the country, the Prefecture of Kankan covers an area of 11564 km^2, with a population of 472112 inhabitants (2014 census) distributed among twelve (12) sub-prefectures plus the urban commune [7]. It is located 377 m above sea level and lies between 9°40 and 10°45 North latitude and 8°18 and 9°45 West longitude. Its climate is Sudano-Guinean with two seasons, a dry season ranging from November to April with the predominance of easterly winds and a rainy season ranging from May to October with rainfall decreasing from South to North. This rainfall rarely exceeds 1200 mm and in general, it varies between 800 and 1500 mm per year, with a maximum in August. The annual average temperature is around 26 °C with an average maximum of 32 °C and an average minimum of 20 °C. In recent years a maximum temperature of over 40 °C has been recorded. The wind regime in Kankan is characterized by four types of wind depending on the time of year with varying directions seasonally [8].

II.1.2 Materials and production equipment

The different materials used for making the device are: metal sheet, black paint, copper pipe, glass, sawdust, two barrels and wood (rafters and planks). The working and measuring equipment are: welding and carpentry equipment, painting, a ruler, a centimeter, a GPS and a thermometer.

Method

Hypotheses

The methodology followed for this study obeys a certain number of hypotheses, namely: the flow of water within the sensor is one-dimensional, the thermo-physical properties of the materials used are constant, the sensor is only the seat of transfer heat, the absorber is thick to absorb almost all of the incident radiation, the temperature of the water at the outlet of the sensor is close to that of the absorber and the temperatures of the various solid media are uniform in a perpendicular plane direction of flow (steady state).

Implementation of the device

The sensor consists of the absorber, coil, glazing, insulation and frame. Thus, the absorber is made of sheet metal painted matt black according to the dimension of the frame 4 mm thick, 2 m long and 0.90 m wide; the coil is made of copper pipe (conduction coefficient K = 387W/m.°K) at 600°K [9, 10] with a total length of 22 m and a diameter of 14mm; the glazing is made up of two pieces of glass 4mm thick, each 0.98 m long and 0.70 m wide, or an area of 1.372 m2; the insulation is made from sawdust; the frame is made of red wood with dimensions of 2.1m in length, 0.705m in width and 8.5cm in height. There are four legs, the front ones are longer than the rear ones.

As for the hot water storage tank, it consists of two metal drums nested one inside the other, separated by 5 cm, the space between these two drums is filled with sawdust to ensure insulation. The inner barrel has a diameter of 58cm and a height of 88cm. The outer barrel has a diameter of 67cm and a height of 98cm. The material for the realization was bought in the market of the urban commune of Kankan.

Experiment

The daily charge of the storage tank is 60 liters of water. Thus, two mercury thermometers graduated from 0 to 100 °C and 0 to 200 °C respectively, made it possible to follow the variation in the temperature of the ambient medium, of the water at the inlet and at the outlet of the sensor; an electronic chronometer made it possible to evaluate the time and a Global Position System (GPS) made it possible to locate the point of installation of the device (latitude in relation to the equator 10°30', longitude 9°45' West, altitude 390 m and oriented to the south).

Principle of the physical phenomenon of the solar water heater

The principle of the physical phenomenon of the solar water heater is based on the three modes of heat transfer: conduction, convection and radiation.

The flux of solar radiation arriving on the glazing passes through it in large part and reaches the absorber where it is partially absorbed. It heats up and emits heat towards the glazing which returns part of it to it. Thus, the glazing and the absorber are in mutual radiative exchange.

The regime being and we are studying the heat exchange of the absorber with the outside, at equilibrium the heat balance is determined by relation 1 [11].

$$\Phi_a = \Phi_u + \Phi_p \qquad (1)$$

The value of the absorbed flux (Φ_a) per unit area of the collector is given by formula 2.

$$\Phi_a = \frac{\alpha_a.\tau_v.G}{1-\rho_v.\rho_a} \qquad (2)$$

The lost flux (Φ_p) is characterized by two quantities (flux lost by the front of the sensor Φ_{pav} and that lost by the rear Φ_{par}). It is determined by formula 3.

$$\Phi_p = K.(T_a - T_{ex}) \qquad (3)$$

The useful flux (Φ_u) is determined by relation 4 [12].

$$\Phi_u = \dot{m}_f.C_f.(T_{fs} - T_{fe}) \qquad (4)$$

The instantaneous efficiency of the flat collector, which determines its thermal performance, is calculated by relation 5 [13].

$$\eta = \frac{\Phi_u}{S_C.G} = \frac{\dot{m}_f.C_f.(T_{fs}-T_{fe})}{S_C.G} = \frac{\alpha.\tau_v.G-K.(T_a-T_{ex})}{S_C.G} \qquad (5)$$

When the incident solar radiation flux becomes weak (in the case of a cloudy sky, for example) the instantaneous efficiency can become zero. The value of the incident solar radiation flux corresponds to the threshold radiation, determined by relation 6.

$$G_s = \frac{K.(T_a-T_{ex})}{\alpha_a.\tau_v} \qquad (6)$$

When the solar radiation becomes too intense and the circulation of heat transfer fluid suddenly stops, the instantaneous efficiency becomes zero and the absorber reaches a limit temperature T_{li}, given by formula 7.

$$T_{li} = T_{ex} + \frac{\alpha_a.\tau_v.G}{K} \qquad (7)$$

Or

ρ_a: Reflection coefficient of the absorber; ρ_v: Coefficient of reflection of the glass; α_a: Absorption coefficient of the absorber; τ_v: Glass transmission coefficient; G: Global radiation in (W/m^2); T_a: Absorber temperature in (°C); T_{ex}: Temperature of the external environment in (°C); K: Global conductance of losses in (W/ °C); $\dot{m}_f = \rho_{eau}.V_{eau}$: Mass flow rate of the heat transfer fluid in (kg/s); $\rho_{eau} = 1000\ kg/m^3$: Density of water; $V_{eau:}$ Volume of water stored in the tank in (m^3); $C_f = 4200$ J/kg. °K: Specific heat of the fluid; T_{fs}, T_{fe} et T_{li}: Fluid outlet and inlet temperatures and limit in (°C); η: Instantaneous efficiency in (%); S_C: Collector area in (m^2).

The steps for making the solar collector are shown in fig 1.

a. Coil welding

b. Coil fixed to the sheet

c. Closing the cash register

d. Solar collector produced

e. Storage tank insulation

f. Solar water heater built

Fig 1: Steps in building the solar collector

Results and Discussions

Results

The various results obtained during this study relate to the meteorological parameters (temperature and solar irradiation of the site) and the temperature variations of the ambient environment, of the water at the inlet of the sensor and at the outlet of the sensor. These results are illustrated by the following curves.

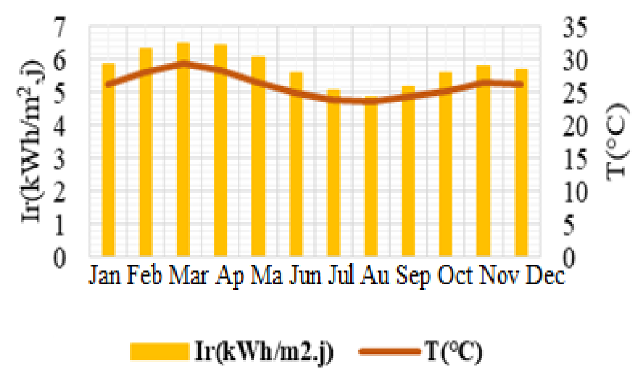

Fig 2: Average annual change in irradiation and temperature

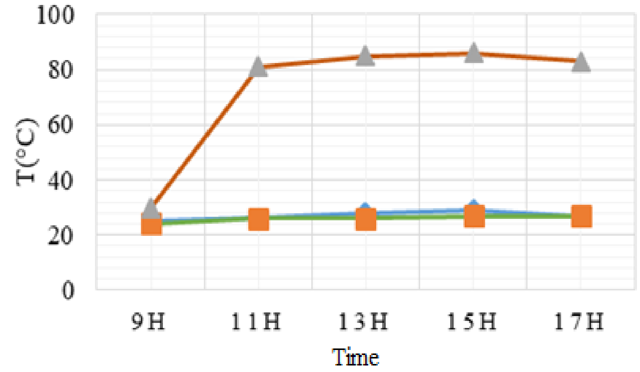

Fig 3: Temperature variation on 01/06/2020

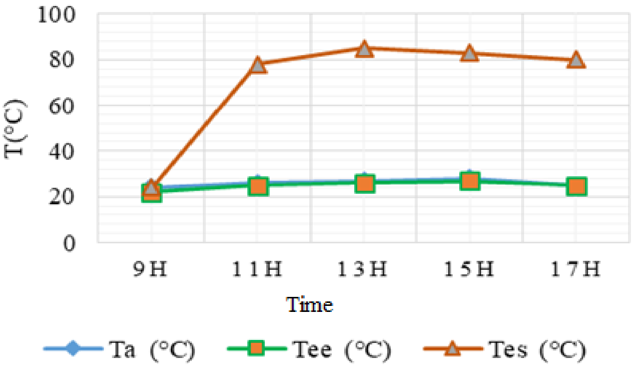

Fig 4: Temperature variation on 01/07/2020

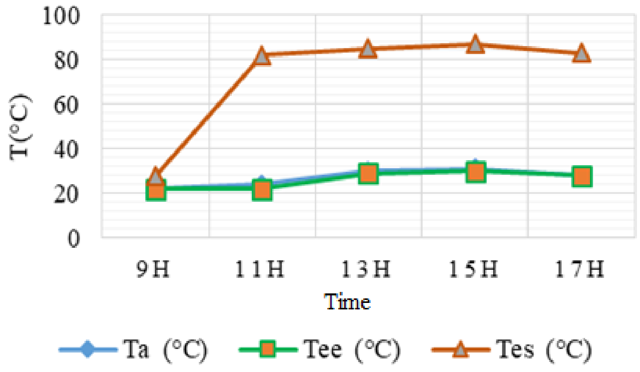

Fig 5: Temperature variation on 01/08/2020

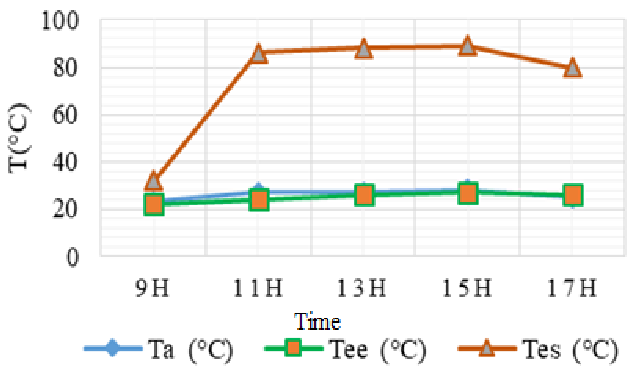

Fig 6: Temperature variation on 01/09/20

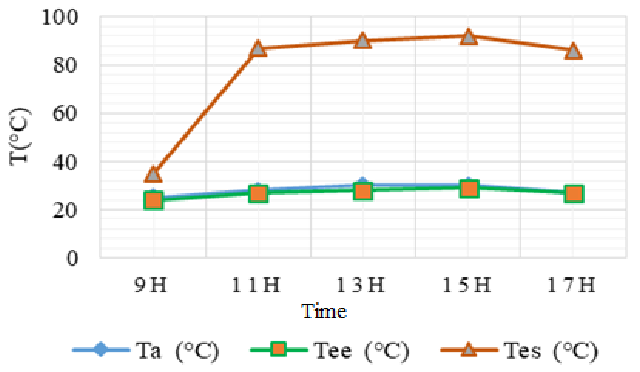

Fig 7: Temperature variation on 01/10/2020

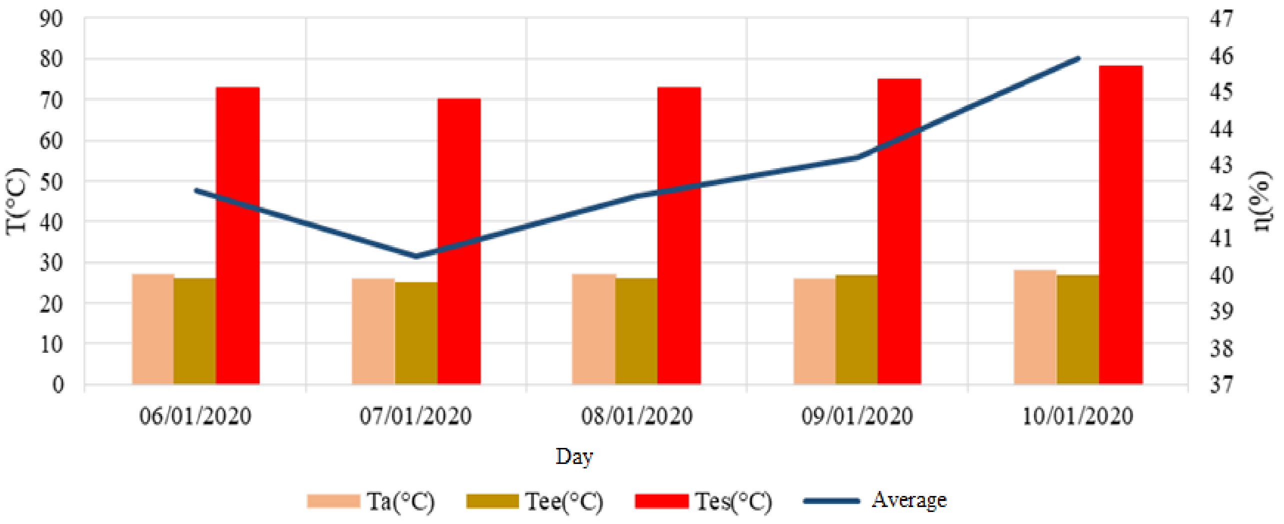

Fig 8: Average daily variation in temperatures and yields

Discussions

Temperature and irradiation of the site

The average annual variations in temperature and irradiation at the site depend on the two seasons of the year (dry and rainy). The lowest values are observed during the rainy season (June to August). They vary from 23.66 °C (4.85 $kWh/m^2.j$) to 29.41 °C (6.51 $kWh/m^2.j$) in August and March respectively, with annual averages of 26.16 °C and 5.75 $kWh/m^2.d$ (Fig 2). The variation of these meteorological parameters has an influence on the performance of the sensor [13].

Temperature and efficiency of the experimentation process

Fig 3 to 7 show that, during the prototype experimentation period (January 6 to 10, 2020), the evolution of the temperature variation in the ambient environment, at the entry and exit of the sensor was a function of days and hours (9 a.m. to 5 p.m.). During this period, the daily temperature variation curves in the ambient environment and the water temperature at the inlet of the sensor are relatively confused from 9 am to 5 pm. The minimum and maximum values during the process are: ambient environment (22 °C and 31 °C) and sensor reentry (22 °C and 30 °C). The averages are 26.8 °C and 25.84 °C respectively.

The curves of daily variations in water temperature at the outlet of the sensor have the same trends, with a low value of 24 °C recorded on 01/07/2020 at 9 a.m. From 11 a.m., there is an increasing variation in temperature for the five (5) days of the experiment, which varies from 78 °C to 87 °C depending on the day. The maximum temperature values at the output of the sensor were recorded from 13 to 15 h, which varies from 85 °C to 92 °C depending on the day. This is the period when solar radiation is very intense and perpendicular to the plane of the collector.

Fig 8 shows that the day of 01/07/2020 was the least sunny, followed 01/06/2020, with a very cloudy sky. The daily average temperatures of the ambient environment, at the inlet and the outlet of the sensor are (26 °C; 25 °C and 70 °C) for 07/01202 and (27 °C; 26 °C and 73 °C) for on 01/06202, which corresponds to the daily returns 41% and 42% respectively.

On 08 and 01/09/2020, the sunshine was favorable with a clear sky, the average daily temperatures recorded are respectively: ambient (27 °C and 26 °C), re-entry (26.2 °C and 27 °C) and the output (73 °C and 75 °C) of the sensor, with yields (42% and 43%). The day of 01/10/2020 was the sunniest with a very clear sky, the different average daily temperatures are as follows: 28 °C, 27 °C and 78 °C. Today's sensor efficiency is 46%. During these five days of experimentation, the average temperatures recorded are: ambient environment (26.8 °C), at the input (26.24 °C) and the output (73.8 °C) of the sensor, with an average efficiency by 43%. This justifies the proper functioning of the system. This performance can be improved by the choice of a better quality absorber, the good adhesion of the storage tank to the absorber and by the addition of a selective coating on the absorber [14].

Conclusion

Analysis of the various results obtained by these series of tests shows that during the collection period of solar radiation and in the vicinity of ambient temperature, the solar water heater produced has an acceptable efficiency of around 40%. It emerges from these results that the performance of a flat solar collector is influenced by the external parameters (sunshine and ambient temperature), the position parameters (orientation, inclination and location of the collector) and the construction parameters (absorber, surface selective, insulating and heat transfer fluid).

The contribution of such a device to the production of hot water and to energy saving is very interesting and its profitability is satisfactory because it reduces the consumption of firewood and fossil fuels which cause the emission of gas. Greenhouse effect. The popularization of the prototype produced could constitute an element in the fight against deforestation, drought and atmospheric air pollution locally.

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