ORIGINAL ARTICLE

THE FLAT-PLATE SOLAR COLLECTOR PERFORMANCE ACCORDING TO THERMO-PHYSICAL PARAMETERS VARIATION

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ABSTRACT

The major challenge of this century is to sufficiently produce energy while preserving the environment. The solar energy is such a response owing to its great abundance and its clean character. One of the most solar energy systems used, because of its technico-economic simplicity, is the flat plate solar collector which aims to provide hot water. In this **context**, an evaluation study is made in CCMS and an experimental measures are realized on the solar collector installed in the Renewable Energy Agency of Mali (REA). The **objective** of these study is to improve the performance of a thermosiphon effect solar collector (solar water heater). To achieve this objective, the **method** consists of using an experimental study in order to validate a numerical simulation model. This simulation model is then used to evaluate the solar collector effectiveness according to the variation of the thickness and the nature of its internal elements (absorber, glass and insulating material). The obtained **results** show that the proposed simulation model is in adequacy with experimental results. In addition, they prove that the solar collector performance is strongly linked to the thermo-physical properties of these elements. In **conclusion**, this study allows to predict the optimal behavior of the flat-plate solar collector before its design.

Keywords: *Solar collector, Simulation, Experimental validation, Performance, Thermo-physical Parameters.*

1. INTRODUCTION

The consumption of global energy has increased exponentially over the past decade. In 2015, it was estimated at one billion oil barrels every 12 days, which is an oil field equivalent [1]. To cover this energy consumption, we have to make appeal to other more promising sources of energy such as the solar energy.

Indeed, this solar energy has an enormous potential, which is estimated at 1694400 Kwh per sunshine year [2]. Besides, to its economic advantages, the development and the use of this energy will be very interesting to environmental protection. Among all possible applications of thermal solar energy, the heating water for domestic use is one of the most simple and less expensive. However, the solar collector performance improvement is a major challenge because, their experimental study is often long and expensive, this requires the numerical tool development capable to study and analyze its thermal behaviour.

Several studies have been carried out to improve the solar collectors' efficiency. Very recent works have studied the analysis of the flat-plate solar collector using nanofluids [3,4]. Other works have improved the solar collector performance by adding a wire coil or forced circulation system or freezing process [5,6,7]. To our knowledge, none of these works are interested in the performance evaluation of a solar collector further to the variation of its internal parameters. Others authors showed that the solar collector efficiency increases proportionately to the specific heat and the flow rate of heat transfer fluid [8,9, 10]. In addition, the authors of [8,10] showed that efficiency decreases when the wind speed increases on the sensor surface. Brahimi (2016) also showed that a glazing thickness decrease or the glazing number increase improves the sensor efficiency [10].

Abdelaziz (2012) showed that the efficiency also depends of the sensor orientation [11]. From this study, authors proved that the flat-plate solar collector with a sun tracking system is less effective than that oriented south facing with variable incline. These studies are based on the geometrical effect (length, width or thickness) of the internal and external parameters; but also on the solar collector efficiency. It should be noted that the solar collector efficiency depends not only on external elements and on the geometry of the internal elements, but especially on the internal nature of elements and

the insulating material thickness. For these reasons, we have decided to lead investigations on the performance evaluation of a solar collector according to the thermo-physical properties of the internal parameters.
The remainder of this paper is organized as follows: the materials and methods are described in section 2 and the results are presented in section 3. In section 4, a results discussion is made and a conclusion is given in section 5.

2. MATERIALS AND METHODS

The experimental study has been made on the solar collector installed to REA of Mali. This solar collector includes two flat plates (the area of each plate is 2,6 m^2) with single glazing, a water tank of 200 l, a fluid circuit which connects the solar collector to tank and a metal support with an inclination of 15° because of the installation site latitude (Bamako).

Firstly, we have used a Benning solar to measure the solar illuminance and thermometers of type 305P and 4-Kanal votcraft to measure the temperatures of absorber, ambient air and those of fluid in solar collector input and output. The tank is filled with water at 7 a.m and the temperatures are measured each 15 min between 8 a.m and 4 p.m. Secondly, we have modeled the solar collector which has been simulated under Matlab/Simulink with the REA solar collector parameters. The comparative study with both methods has showed that the proposed simulation model is in line with experimental results. Finally, the proposed simulation model has been used to evaluate the solar collector performance according to thermos-physical parameters variation. The photo figure of these materials is given by the figure 2-1.

Thermometer 305P

4-Kanal thermomter of votcraft

REA solar collector

Benning solar

Figure 2-1: Photo figure of solar collector and measuring devices.

The solar collector elements exchange some energy between them. This exchange is made by convection, conduction or by radiation. From the energy balance on each element, we can modelize the solar collector as follows [8, 10, 12, 13]:

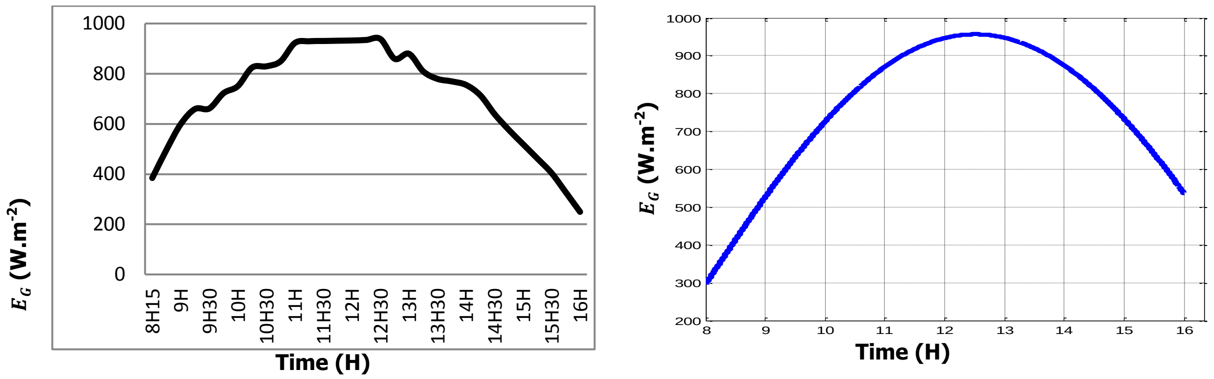
$$\begin{cases} \dfrac{dT_V}{dt} = \dfrac{1}{M_V C_{P\,V}} \begin{bmatrix} \alpha_V S_V E_G + h_{r\,(ab-V)} S_V (T_{ab} - T_V) + h_{conv} S_V (T_{ab} - T_V) \\ - h_{conv\,(V-amb\,)} S_V (T_V - T_{amb}) - h_{r\,(V-ciel)} S_V (T_V - T_{ciel}) \end{bmatrix} \\ \dfrac{dT_{ab}}{dt} = \dfrac{1}{M_{ab} C_{P\,ab}} \begin{bmatrix} \tau_V \alpha_{ab} S_{ab} E_G - h_{r\,(ab-V)} S_{ab} (T_{ab} - T_V) - h_{conv} S_V (T_{ab} - T_V) - \\ h_{conv\,(ab-flu)} S_{flu-ab} \left(T_{ab} - T_{flu}\right) - \\ (h_{cond\,(ab-arr\,)} + h_{cond\,(ab-later\,)}) S_{iso} (T_{ab} - T_{iso}) \end{bmatrix} \\ \dfrac{dT_{flu}}{dt} = \dfrac{1}{V_{flu} \rho_{flu} C_{P\ flu}} \begin{bmatrix} h_{conv\,(ab-flu)} S_{flu-ab} \left(T_{ab} - T_{flu}\right) - \\ h_{cond\,(flu-iso)} S_{iso} \left(T_{flu} - T_{iso}\right) \end{bmatrix} \end{cases} \qquad (1)$$

Where T_V, T_{ab} , T_{flu}, T_{amb} represent respectively the temperatures of the glazing, the absorber, the fluid and the ambient environment. E_G represents the solar illumination and the chosen model in this study is the empirical model of Perrin Brichambaut because of its adequacy with the experimental data [14]:. S, α, τ represent the collector area, absorption coefficient and transmission coefficient. h_{conv} , h_{cond} , h_r are respectively the convection, conduction and radiation coefficients.

3. RESULTS

3.1 Simulation and experimental validation:

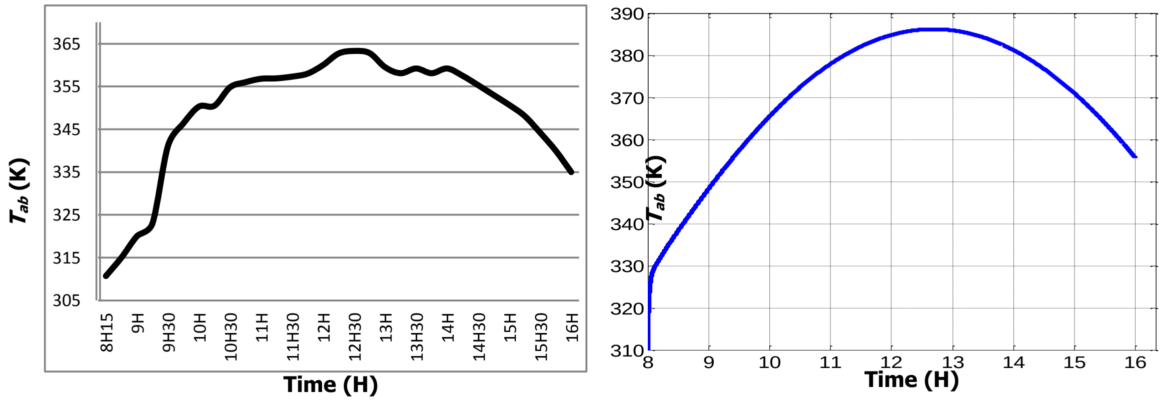
The elaborated mathematical model is simulated over 8 hours ((from 8 a.m to 4 p.m) by using the R.E.A solar collector characteristics. The obtained results are illustrated by the following figures:



a. Experimental curve

b. Simulated curve

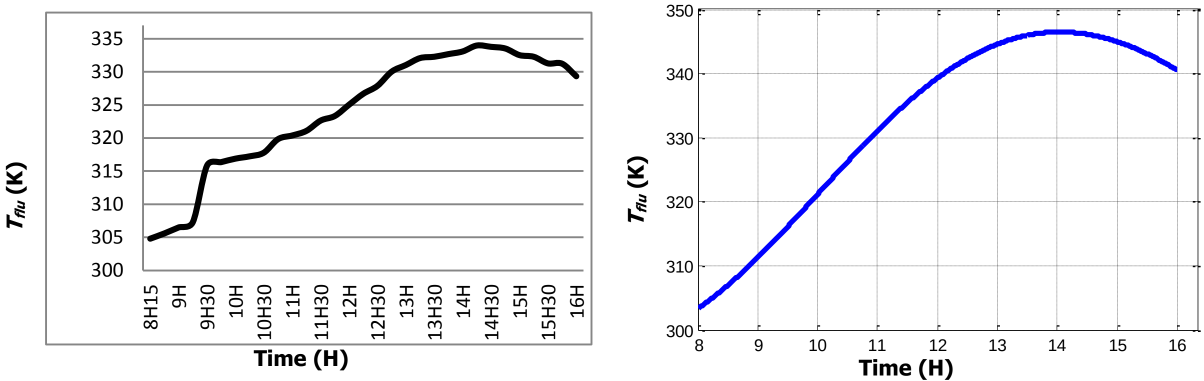
Figure 3-1: Solar illuminance.



a. Experimental curve.

b. Simulated curve.

Figure 3-2: Absorber temperature.



a. Experimental curve.

b. Simulated curve.

Figure 3-3: Fluid temperature.

3.2 Study of performances: The instantaneous yield is the ratio between the useful flow transmitted to the fluid and the incident solar flow on the solar collector surface, it is noted η. Its expression is given by [13, 15, 16]:

$$\eta = \frac{\varphi_u}{S_{ab} E_G} \tag{2}$$

A part of the flow absorbed by the absorber is transmitted in the fluid and the other part is lost towards the outside environment. This absorbed flow is described as follows [17, 18]:

$$\varphi_{ab} = \varphi_u + \varphi_{per}$$

The useful flow expression is given by the below equation:

$$\varphi_u = \varphi_{ab} - \varphi_{per} = \tau_V \alpha_{ab} S_{ab} E_G - U_P S_{ab} \left(T_{ab} - T_{amb} \right) \qquad (3)$$

The instantaneous yield expression becomes:

$$\eta = \eta_0 - \frac{U_P \left(T_{ab} - T_{amb} \right)}{E_G} \qquad (4)$$

Where:

$\eta_0 = \tau_V \alpha_{ab}$: Optical yield

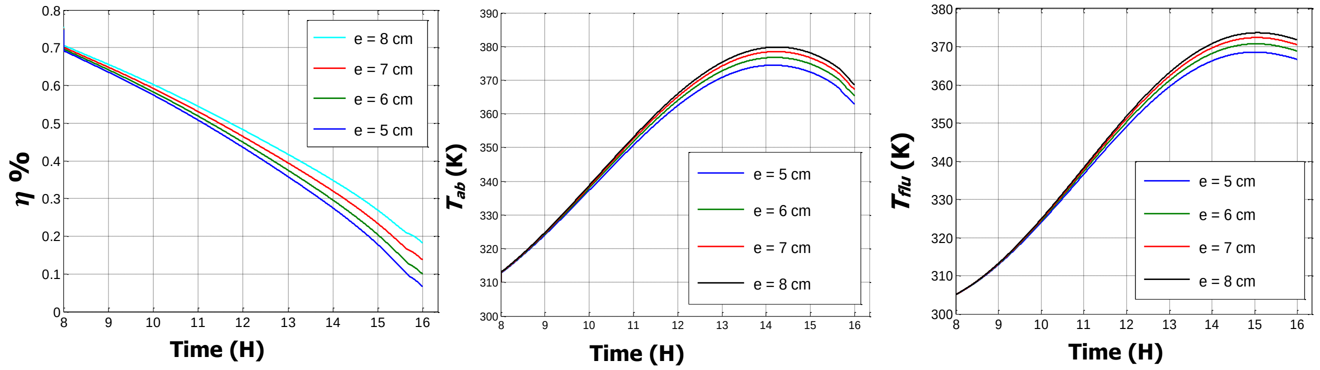
E_G : Solar illuminance (W.m^{-2}),

U_P : Global coefficient of losses (W.m^{-2} K^{-1}),

$T_{ab}\ et\ T_{amb}$: respectively absorber and ambient environment temperatures (K).

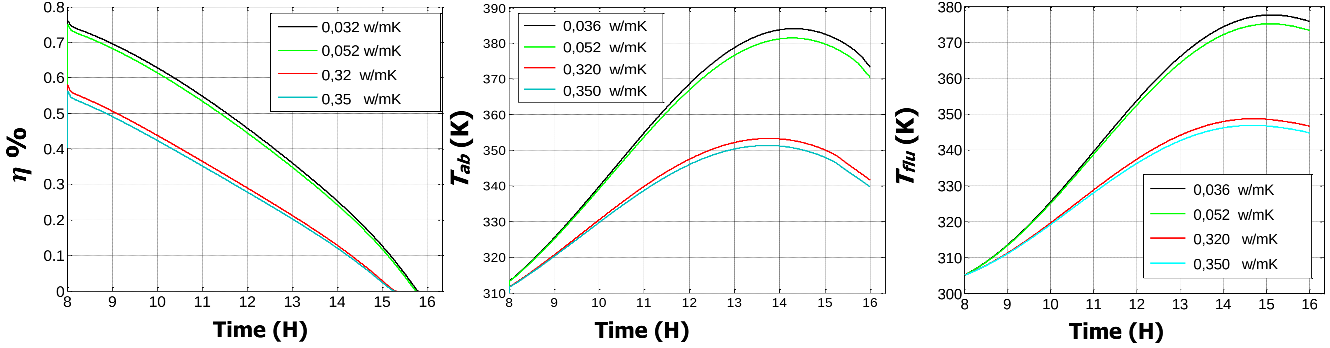
To improve the solar collector efficiency, we studied in simulation the influence of four internal parameters on this efficiency. These parameters are: the transparent cover nature, the absorber nature, the nature and the thickness variation of insulating material.

A first simulation is made by making vary the insulating material thickness from 5 to 8 cm with step of 1cm.
The second simulation is made according to the nature variation of insulating material. For that purpose, four types of insulating material of same thickness and different thermal conductivity were used. These insulations are the polystyrene foam (0.036 W.m^{-1}.k $^{-1}$), the plaster (0.35W.m^{-1}.k $^{-1}$), the polyethylene (0.32W.m^{-1}.k $^{-1}$) and the calcium silicate (0.052 W.m^{-1}.k $^{-1}$).
The third simulation is made according to the nature variation of the absorbent plate. For that purpose, four absorber types of same thickness were used. These absorbers are: the black chrome steel, the galvanized steel, the aluminum and the copper.
A last simulation is made by making vary the transparent cover nature. The used covers are the glass clear, the glass low content in Fe_2O_3, the prize-winning glass and the plastic (or Plexiglas)
The obtained results are illustrated as follows:



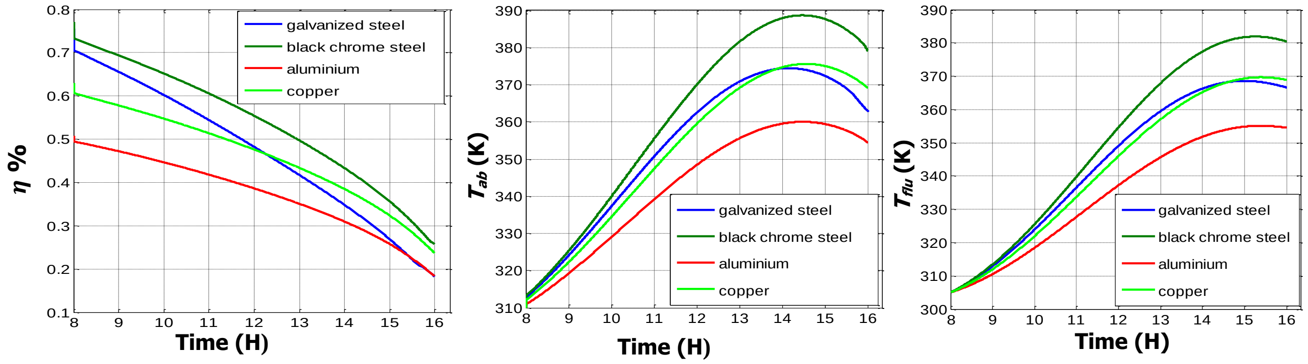
a. Instantaneous yield b. Absorber temperature c. Fluid temperature.

Figure 3-4: Insulation material thickness influence



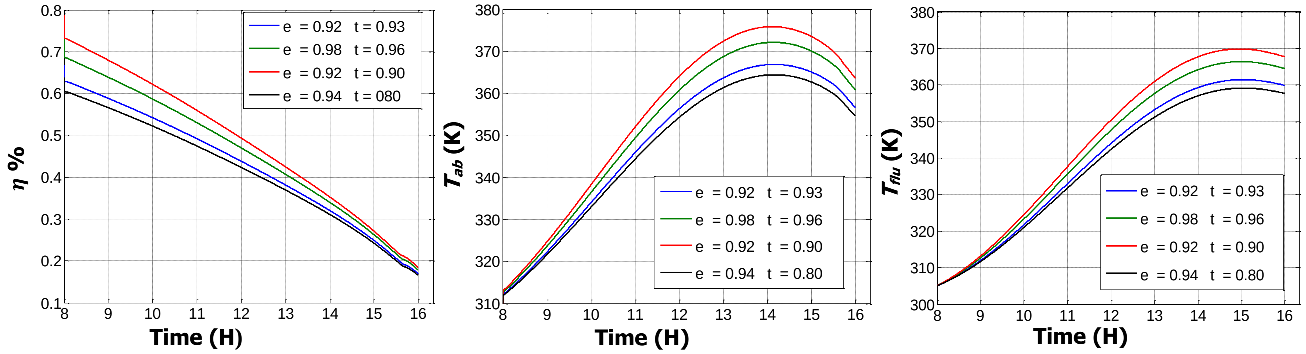
a. Instantaneous yield. b. Absorber temperature. c. Fluid temperature.

Figure 3-5: Thermal conductivity influence of insulation material



a. Instantaneous yield b. Absorber temperature c. Fluid temperature

Figure 3-6: Absorber nature influence



a. Instantaneous yield b. Absorber temperature c. Fluid temperature

Figure 3-7: Transparent cover nature influence

4. DISCUSSION

Experimental and simulated curves (Figure 3-1, a and b) of the illuminance present the same shape. They progress within first hours of the day. The reached maximal values are 932 W.m^{-2} for the experimental curve and 956 W.m^{-2} for the simulated curve, the gap between these two values is evaluated at 2, 5 %. The both absorber temperature curves progress at the beginning of the day according to the solar illuminance (Figure 3-2, a and b). The experimental curve presents a maximum of 363K in 12h45mn while the maximum of the simulated curve is 385 K at 1 p.m. The error between these two maximal temperatures is estimated at 5, 7 %. The fluid and the absorber temperature curves vary according to the solar illuminance received on the collector surface. The error between the average temperatures of the fluid (Figure 3-3, a and b) is estimated at 3.46 %. The simulation results are in adequacy with those of the experimental validation. This model which is developed will be used after studying the solar collector efficiency according with internal parameters variation.

Globally, we observe a decrease of the yield over the study period (from 8 a.m till 4 p.m), it can be explained by the increase of radiative losses as the absorber is heating and while it cools. The efficiency evolves proportionally according with thickness variation of insulating material (Figures 3-4 a). This result is due to the losses decrease by conduction in the insulating material and the fluid and absorber temperatures increase (Figures 3-4 b and c). We also observe a decrease of efficiency according to the thermal conductivity increase of insulating material (Figure 3-5 a). Consequently, the temperatures of fluid and absorber increase when decreasing thermal conductivity (Figure 3-5, b and c). In addition, we notice that the absorber and fluid temperatures (Figure 3-6 b and c) with black chrome steel are higher compared to those other plates, consequently, it presents the best yield with respect to other types of absorber (Figure 3-6 a). This result can be explained by the low emissivity of this plate which reduces radiative losses and its high absorptivity which is due to the selective layer. Finally, the simulation results show that the efficiency is better with a glass cover at low content in Fe_2O_3 (Figure 3-7 a), this is due to the high transmissivity of this cover with respect to small wavelength solar rays and his weak emissivity which reduces radiative losses.

5. CONCLUSION

In this paper, we studied the solar water heater with thermosiphon effect efficiency according to the variation of some parameters of its internal elements. For that purpose, a model of solar collector was proposed on the basis of the energy balance. This model was simulated and the results were compared with those obtained on the solar collector installed in the REA of Bamako (Mali). These results proved that the proposed model is valid to study the thermal behavior of this collector type. Finally, this model was used to estimate in simulation the efficiency of the solar collector further to the variation of some internal parameters such as: the insulating material thickness, its nature, the absorber and the transparent cover nature. This study results reveal that the solar collector efficiency can be clearly improved with:

- A low emissivity and a high transmissivity of transparent cover,
- A low thermal conductivity and a thickness increase of insulating material,
- A low emissivity and a high absorptivity of the absorber covered by a selective layer.

Besides proposing a simulation model, this study offers to the professionals and to the designers of solar collector a tool which allows to study, analyze and improve the thermal behavior of a solar collector before its practical design.

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6. REFERENCES

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