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Study and Modelisation the Parameters of Plate Solar air Collector at Single Pass for Drying of Madagascar CocoaBeans

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ABSTRACT*: In this paper, the authors discuss an experimental study and modelisation of the parameters of a plane solar collector at single pass.The authors construct a prototype of the indirect solar dryer, in order to compare the theoretical and experimental values between the absorber, the heat transfer fluid and the ambient air in the presence of a natural convection.This apparatus is intended for drying agri-food products, in particular cocoa beans. The modeling is based on the analysis of the thermal exchanges of each element and the evolution of the global solar power whatever the position of the captor.*

Keywords: *plate solar air collector, theoretical and experimental studies, solar energy, free convection.*

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Nomenclature

Roman lettersymbols

C_p	specific of heat transfer fluid, (J/kg.k)
C_{pi}	calorific capacity of insulation,(J/kg.k)
C_{pn}	calorific capacity of the absorber,(J/kg.k)
C_{pv}	calorific capacity of the glass,(J/kg.k)
D_h	hydraulic diameter, (mm)
e_p	thickness between glass and absorber,(mm)
h_{cv}	conductive transfer coefficient of the glass,(W/m^2.K)
h_{ci}	conductive transfer coefficient of the insulation, (W/m^2.K)
h_{crv}	radiative transfer coefficient between the glass and thecelestial vault,(W/m^2.K)
h_{rnv}	radiative transfer coefficient between the glass and absorber,(W/m^2.K)
h_{rni}	radiative transfer coefficient between absorber insulation, (W / m^2.K)
h_{ris}	radiative transfer coefficient between insulation and floor, (W / m^2).
h_{vv}	convective transfer coefficient of the glass, (W / m^2.K)
h_{vvn}	convective transfer coefficient between glass and absorber, (W / m^2.K)
h_{van}	convective transfer coefficient between drying air and absorber, (W / m^2.K)
h_{vai}	convective transfer coefficient between drying air and Insulation, (W / m^2.K)
Io	radiation received by a horizontal surface outside atmosphere, (J / m^2.day)
I	solar Constant, (w / m^2)
J	day number in the year
Gz	Graetz number
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
T_c	temperature of the celestial vault (°C)
T_f	air flow temperature (°C)
T_a	ambient Temperature (°C)
T_{ii}	temperature inside of the Insulation (°C)
T_{ie}	temperature outside of the Insulation (°C)
T_n	temperature of the absorber (°C)
T_s	temperature of the floor(°C)
T_{ve}	temperature outside face of the glass (°C)
T_{vi}	temperature inside face of the glass (°C)

Greek letter symbols

α	absorption coefficient
αn	absorption coefficient of absorber
β	sensor angle of inclination, (°)
ε	emissivity
υ	dynamic viscosity (kg / m.s)
ν	kinematic viscosity (kg / m.s)
ρ	density of the fluid (kg / m3)
σ	constant of Stephan Boltzmann
αv	coefficient of absorptivity of the glass

I. INTRODUCTION

Various applications of thermal transfer in the solar drying field have led to numerous studies, both theoretical and experimental, due to their importance in numerous scientific and engineering applications.In this paper, we have modeled the thermal exchanges between the elements of the captor by comparing the values obtained by calculations and those of the experiment of the present prototype.Much of the work has already been published on modeling of flat plate solar collector. Among them, references like F. Aissaou et al [1] presented an experimental and theoretical analysis on the thermal performance of the apartment.The system is to simulate the

Transfer of heat in single pass in forced convection. At first, a study is experimentally based on the use of thermocouples to measure the different temperatures of each element and then the problem is handled numerically.They found the results to be in close agreement with the experimentally measured values.

V. Santosh et al. [2] have approached an experimental study at the laboratory scale and are developing a thermal performance test of the apartment solar plate heaters with simulated solar radiation intensity.All experiments are carried out with an artificial solar system and the presence of natural convection. The performances of these three models were compared on the basis of the overall thermal efficiency and the thermal gradient along the normal to the base.The thermal gradient was determined by the laser beam deviation method. The temperature sensors were also used to validate the optical results of the thermal gradient. The efficiency of these models was found respectively and they also showed that the thermal gradient tends to decrease with increasing overall thermal efficiency.S. Kumar et al. [3] contributed to the use of three-wire meshes (sand, coal and wood) to analyze the performance of the solar air heater. They carried out experiments to improve this performance and found that the maximum temperature difference was 290 ° C.

S.Shanmuga et al. [4] modeled and manufactured a one-pass solar water heater in three different types of solar heating with natural circulation passing before collectors under test conditions. Some parameters have been determined theoretically and experimentally. This study gives the basic knowledge and processes behind the analysis and modeling of a single solar air passage.Ali Grine et al. [5] presented an analytical modeling of heat transfer in a hot air generator. Other researchers such as Baissi et al. [6] presented a theoretical and experimental study of a solar collector. They also compared its theoretical and experimental results of solar irradiance, ambient temperature and fluid output.S. Oudjedi et al. [7] discussed a study of the parameters of insolator and showed that their results correspond perfectly to the necessary factors and parameters of the drying chamber.

In view of all research on the design and production of a hot air generator, this prototype is also of great interest in the sustainable development of the third world.

II. MATERIAL AND METHODS

2.1 Description of plate solar air collector

The plate solar air collector studied is a single pass air insolator.The heat transfer fluid circulates between the lower face of the absorber and the upper face of the insulator. The figure 1 shows the elements of the insolator and the different types of heat transfer involved. It is composed of a pane on its front, an absorbing plate in galvanized steel painted in black and insulation on its rear face.

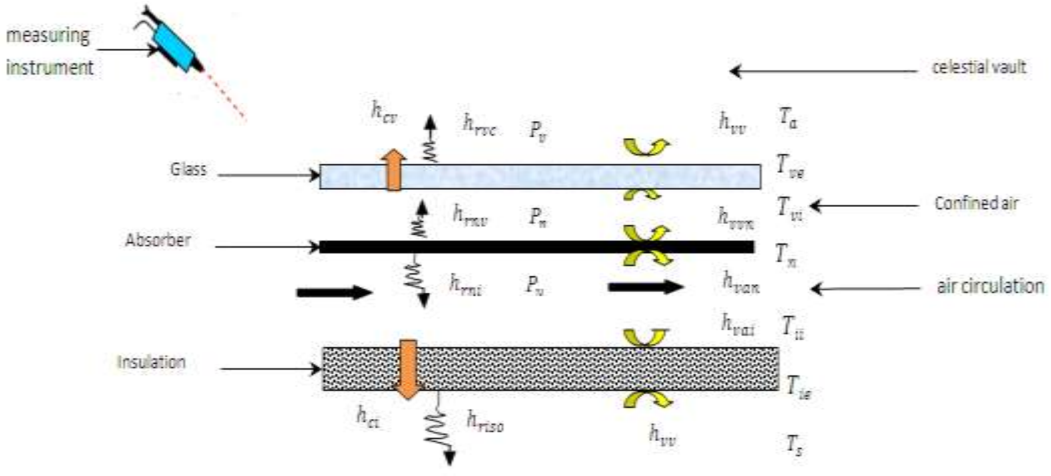

Fig.1:*Schematic representation of the plate solar air collector to one glazing*

2.2 Method of obtaining experimental results

Two thermometers are installed on both ends of the sensor, one of which is graduated from -50 ° C to + 50 ° C at the inlet to measure the inlet temperature of the fluid and the other from 0 ° C to 120 ° C is intended for measuring the temperature of the fluid at the outlet.

Varieties of infrared gun pyrometers were used for measurements. This prototype used is constructed from locally available materials, which operate according to the principle of free convection.This type of dryer is lessexpensive, simple to make and suitable for drying agri-food products. This work will present the results of a theoretical and experimental study of the parameters of the captor.

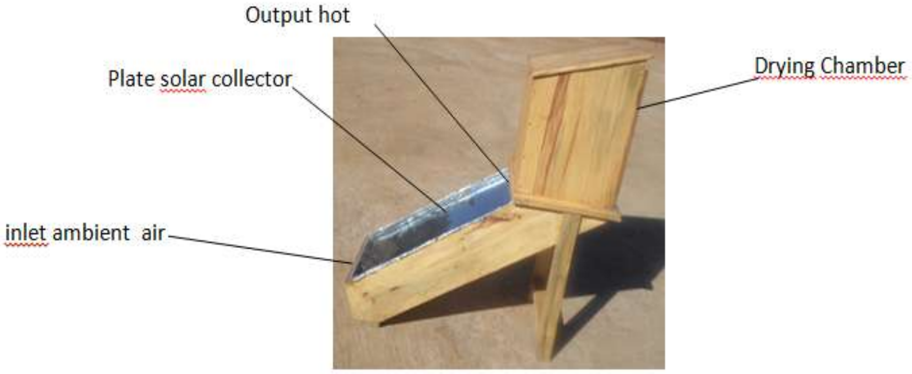

Fig. 2 :*Static dryer prototyp*

III. MATHEMATICAL MODELING

The modeling of plate solar collector necessarily takes into consideration the mode of circulation of the fluid against the number of glazing, the presence of the absorber and the material of the insulation used.This modeling must lead to the determination of the coefficients characterizing the captor studied and the different equations allowing to evaluate the extracted energy.

Before discussing the calculations, it is necessary to consider certain assumptions:

- The physical and thermal properties of the heat transfer fluid (air) are given as a function of its mean temperature.
- The absorber is made of galvanized steel of very small thickness with a very high conductivity.
- The two faces of the glass are at the same temperature.
- The ambient temperature is the same around the captor.
- The fluid temperature and in the absorber depends only on the longitudinal dimension (direction of the flow).
- The air must circulate between the lower face of the absorber and the upper face of the thermal insulation.

3.1 Modeling of heat exchanges

In our simulation we use the step-by-step method which takes into account the temperature evolution of all the elements of the captor in fictitious slices of length dx in the direction of the flow of the fluid.

3.1.1 Balance sheet of heat exchanges

Outside face of the glass

$$\frac{M_v C_{pv}}{Surf}\left(\frac{dT_{ve}}{dt}\right) = \frac{P_v}{2} + h_{rve}(T_c - T_{ve}) + h_{vv}(T_a - T_{ve}) + h_{cv}(T_{vi} - T_{ve}) \qquad (1)$$

Inside face of the glass

$$\frac{M_v C_{pv}}{Surf}\left(\frac{dT_{vi}}{dt}\right) = \frac{P_v}{2} + h_{cv}(T_{ve} - T_{vi}) + h_{rnv}(T_n - T_{vi}) + h_{vvn}(T_n - T_{vi}) \qquad (2)$$

At the absorber

$$\frac{M_n C_{pn}}{Surf}\left(\frac{dT_n}{dt}\right) = h_{rnv}(T_{vi} - T_n) + h_{vvn}(T_{vi} - T_n) + h_{van}\left(T_{(j-1)} - T_n\right) + h_{rni}(T_{ii} - T_n) + P_n \qquad (3)$$

Inside face of the insulation

$$\frac{M_i C_{pi}}{Surf}\left(\frac{dT_{ii}}{dt}\right) = h_{vai}\left(T_{(j-1)} - T_{ii}\right) + h_{ci}(T_{ie} - T_{ii}) + h_{rni}(T_n - T_{ii}) \qquad (4)$$

Outside face of the insulation

$$\frac{M_i C_{pi}}{Surf}\left(\frac{dT_{ii}}{dt}\right) = h_{ci}(T_{ii} - T_{ie}) + h_{ris}(T_s - T_{ie}) + h_{vv}(T_a - T_{ie}) \, (5)$$

At the heat transfer fluid

$$\frac{QC_p}{Surf}\left((T_{(j)} - T_{(j-1)}\right) = h_{van}(T_n - T_{(j-1)}) + h_{van}(T_{ii} - T_{(j-1)}) = h_{van}(T_n + T_{ii} - 2xT_{(j-1)} \qquad (6)$$

3.1.2 Radiation heat exchange

Between outside face of the glass and celestial vault

$$h_{rvc} = \sigma.\varepsilon_v(T_c + T_{vc})(T_c^2 + T_{vc}^2) \quad (7)$$

with: $T_c = 0.0552.T_a^{1,5}$ (8)

Between inside face of the glass and absorber

$$h_{rnv} = \sigma.\varepsilon_{v.}\varepsilon_n \frac{\left(T_{vi} + T_n)(T_{vi}^2 + T_n^2)\right)}{\varepsilon_v + \varepsilon_n - \varepsilon_v\varepsilon_n} \quad (9)$$

Between absorber and inside face of the insulation

$$h_{rni} = \sigma.\varepsilon_{ii}.\varepsilon_n \frac{(T_{ii} + T_n)(T_{ii}^2 + T_n^2)}{\varepsilon_{ii} + \varepsilon_n - \varepsilon_{ii}\varepsilon_n} \quad (10)$$

Between outside face of the insulation and floor

$$h_{ris} = \sigma.\varepsilon_{is}(T_{is} + T_s)(T_{is}^2 + T_s^2) \quad (11)$$

3.1.3 Thermal exchange by conduction

The coefficient across the glass and insulation

$$h_{ci} = \frac{\lambda_i}{e_i} \quad (12)$$

3.1.4 Heat exchange by convection

Upper face of glass

$$h_{vv} = 5{,}67 + 3{,}86.Vv \quad (13)$$

Between the glass and the absorber

$$h_{vvn} = \frac{N_u\lambda_a}{e_p} \quad (14)$$

with :$Nu = h_{cn,f}.D_h$,(15)

The coefficient across the glass and insulation

$$h_{van} = h_{vai} \quad (16)$$

3.1.5 Ambient temperature

$$T_a = \frac{(T_{a,mx} + T_{a,min})}{2} + \frac{(T_{a,max} - T_{a,min})}{2}.\cos\left(\frac{2.\pi}{P_{er}}(T_L - T_{e,max})\right) \quad (17)$$

IV. RESULTS AND DISCUSSION

The figure.3 illustrates the curves representing the variation of the powers of the glass and the absorber. The absorber curve is important because of its higher absorption coefficient than the glass because of its optical properties, allowing the heat to pass through with a high transmission coefficient.Figure 4 shows that the value of the overall solar power varies with the positioning of the sun. The smaller the distance between the sun and the collector, in general, the case of 12 o'clock, the greater the radiation, because there is less atmospheric mass to be crossed. On the other hand, if the sensor is in an inclined position, the solar radiation is less important.

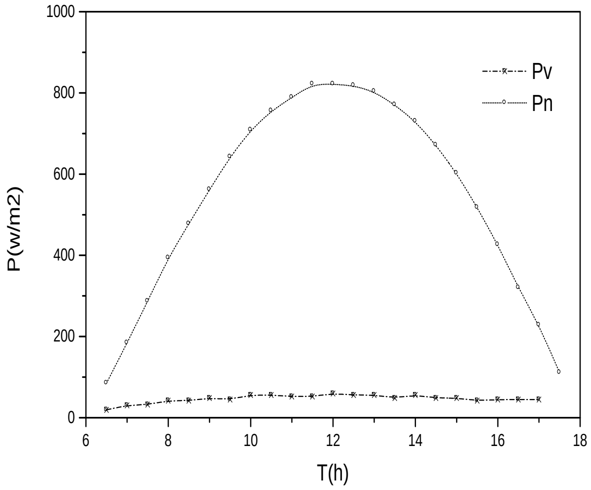

Fig. 3 :*Evolution of the powers of the glass (Pv) and the absorber (Pn) against of time*

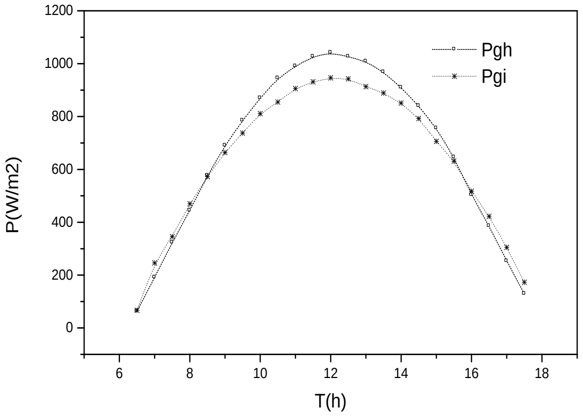

Fig. 4: *Global solar powers evolution on the horizontal plane (Pgh) and inclined (Pgi) against of time*

The curves representing the evolution of the fluid temperatures and of each element of the captor are shown in figure.5. In decreasing order of value, the absorber holds the highest temperature due to the higher absorption coefficient.In this same figure, we also presented the temperature changes of each element of the sensor in order to better verify our computation code for the present prototype. However, we will limit ourselves to the comparisons of the temperatures evolutions of the absorber, the heat transfer fluid and the ambient air due to their importance in a hot air generator.

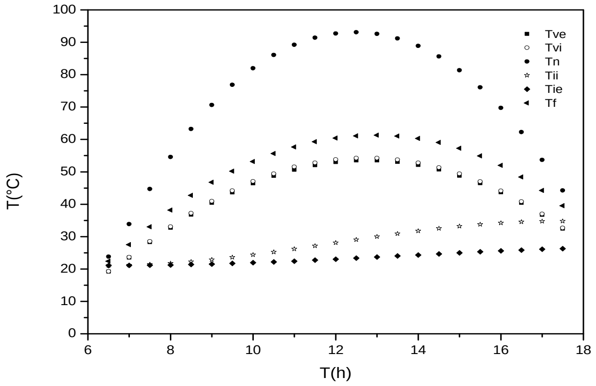

Fig. 5 : *Evolution of the fluid temperature and of each element of the collector against of time*

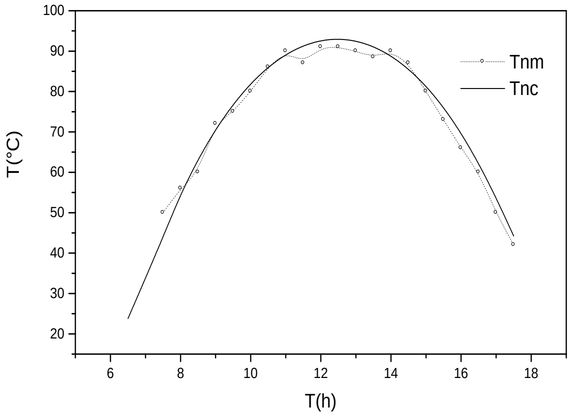

Fig. 6.a : *Comparison between the temperature of the calculated absorber (Tnc) and the measured (Tnm) against of time*

Figures 6a, 6b and 6c respectively represent the comparisons of the calculated and measured results of the temperatures of the absorber, the outlet of the heat transfer fluid and that of the ambient air. Theoretical and experimental values have shown that the relative deviations do not exceed 5% in all three cases.The results obtained have had a great agreement between the theoretical values of departure and those measured during the periods of sunshine and in the most unfavorable case.

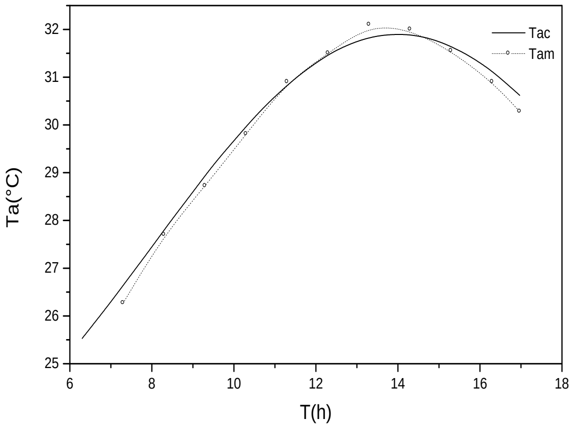

Fig. 6.b:*Comparison between the outlet temperature of the calculated heat transfer fluid (Tfc) and the measured temperature (Tfm) as a function of time*

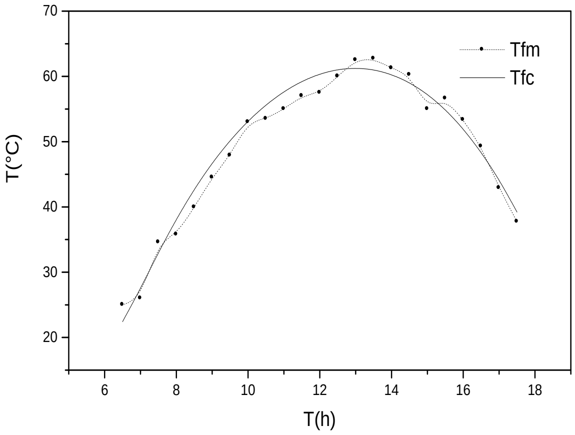

Fig. 6.c:*Comparison between the calculated ambient temperature (Tac) and the measured temperature (Tam) as a function of time*

Among other things, it is possible, thanks to the quality of precision of the measuring instruments used and to the perfection of the design of the prototype as a whole and in particular the elements of the captor.Moreover, the curves of the temperature variations of these elements have been obtained and correspond to the governing physical laws, thanks to the study of the superior quality of the materials used in the design and realization of this prototype.Indeed, we can confirm that the realization of the apparatus on a large scale is conceivable due to the availability of local materials existing in the region.

V. CONCLUSION

In this paper, we describe the behavior of the elements of a single-pass solar air collector between the absorber and the insulation destined to drying the cocoa beans using the numerical modeling of the heat exchange equations.

The results obtained, whether theoretical or experimental, generally depend on the physical characteristics of the dimensions and positions of the collector, the weather conditions and the field of application (heating, drying or other).This captor mates with a drying chamber and the temperature of the air at the outlet of the captor is then of that the air intake of the drying chamber. It is observed that the figures relating to the experimental results coincide well with that of the calculation. In the comparison, the difference is of the order of less than 5% and it seems reasonable to conclude that the agreement is good.

However, the physical and chemical characteristics of the cocoa beans were addressed during the measurements. The results confirmed that the behavior of the generator responds perfectly to the process demanded by the product. In general, the cocoa beans had to be fermented before being dried. Then, the curves of the temperature fluctuations of the heat transfer fluid corroborate on demand for the product studied.

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