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# Laboratory Simulation of Solar Dryer for Tropical Woods: The Case of Ebony (*Diospyros Crassiflora*)

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## Abstract

In the present paper, a numerical modeling of solar dryer is doing. This solar dryer operates in the natural convection condition and his construction is not difficult because, local materials are used and it is not necessary to follow a particular formation. We have obtained a numerical solution which explains experimental solution. Application is doing on ebony wood that is a wood most difficult to dry and most utilized for the sculpture. With 30mm of thickness, the sample passed 25 days to reduce his water content to 15%, initial water content was equal to 27%, and the drying period is the month of March from the town of Yaoundé, political capital of Cameroon. This modeling proposed is a modest contribution to explain the solar drying of tropical woods at the laboratory scale.

***Keywords:*** *Tropical woods, solar drying, modeling, numerical simulation, experiment, diospyros crassiflora.*

## 1. Introduction

Solar energy is much used in South and North Africa regions for to dry biologic products for many reasons: this energy is free and his flux is important. This energy is also clean, consequently, development and promotion of solar energy is an alternative solution to optimize fossil energy and to satisfy imperative need of many populations. In the literature, many applications of the solar energy are explained in order to reduce poverty and global climate changes [1,2,3]. Before utilization of wood, the drying permits to reduce water content in order to stabilize a plank of wood. Specialists recommend using a drying table of each wood type. But only, the drying process is good when after, we obtained a good quality of wood, a small consummation of energy during the process, a small damage of atmosphere for a small drying time. In these reasons, it is much important to construct the dryers which satisfied these three conditions quoted above. The dryers of food products are various, because a much studies are detailed in the literature [4,5,6]. Some hybrids solar dryers or not are showed in the literature [7]. Formation and technical assistance are important when we want to ameliorate the drying in these dryers. Numerical simulation to predict experimental values is a good tool to calculate the dimensions of all component of the dryer in order to obtain a precise efficacy. In this paper, we modeling and simulated the functioning of a simple wood indirect solar dryer. The similarity studies are doing in the literature on the expensive dryers which use solar captors [8,9,10] or with the glazed walls [11,12]. Application are doing on ebony wood (*Diospyros crassiflora*) coming from forest of the South-Cameroon region.

## 2. Experimental Protocol

Two samples of ebony wood are used with initial dimension 20x12x3cm$^3$. The samples are dressed between the plinth and the floor. We have used numerical scales of Sartorus mark in the model BL12. The capacity and the precision of the scales are respectively 12kg and 0.1g. This scales permits to obtain mass evolution wood sample during the process. Relative humidity and drying air temperature are obtained with thermohygrometer of the mark HRT100 with the precision is 1% for relative humidity and 1°C for the temperature.

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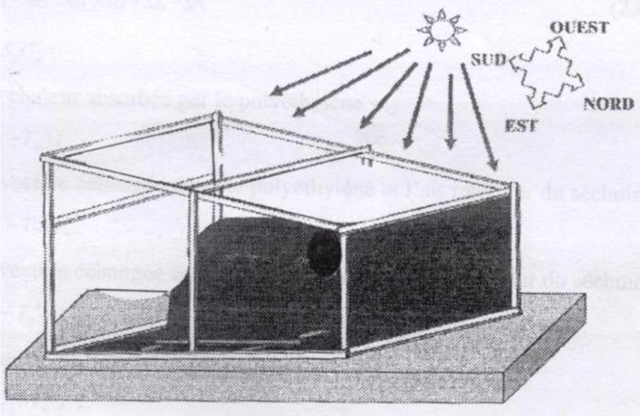
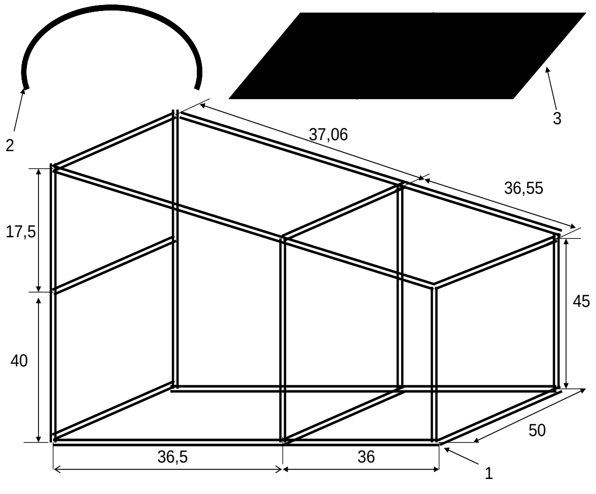
## 3. Solar Dryer Design

It is a passive solar dryer in the scale of laboratory (figure 1). These components are constitute of one envelop in plastic (polyethylene) which is hanged on the sticks in anhydrous ayous wood because, it is less costly, available and light. The face above is inclined plane with 10°. The plinth is do in sheet-metal to paint in black (black body) permits the air of dryer to keep up the temperature during a night and the other time that the irradiation is not good. The laboratory dryer operates without air recycling. The plastic membrane and the sheet-metal have respectively a thickness equal to 0.35mm and 0.5mm.



a) Position of the dryer during the drying



b) Dimension of the dryer in the scale of laboratory

**Fig.1.** Experimental solar dryer (Dimension in centimeter unit)
Indications: 1) wall, 2) plinth, 3) floor

## 4. Modeling

The modeling of a unit of wood solar dryer is most complex for many reasons:

- solar irradiation is function of the site and is non constant during a day;
- the wood to dry is hygroscopic;
- a heat loss in the dryer unit and initial conditions of components of the dryer are always unknown;
- In our modeling, we have used a following simplified hypothesis:
- hygrometry of ambient air out of dryer is supposed monthly constant;
- thermal mutual exchanges between the walls of dryer are neglected;
- temperature and humidity of the samples and the others components of the dryer are uniform in each time.

### 4.1. Equations of the model

-Heat transfer on the wall:

$$m_p C_p \frac{dT_p}{dt} = S_p G_t \alpha_p + S_p \sigma_s F_{pto}\left(T_{to}{}^4 - T_p{}^4\right) - S_p h_{ci}\left(T_p - T_a\right) - \\ S_p \sigma_s \varepsilon_p \left(T_p{}^4 - T_{ciel}{}^4\right) - S_p h_{vv}\left(T_p - T_{ab}\right) \tag{1}$$

- Heat transfer on the sheet-metal (black body):

$$m_{to} C_{to} \frac{dT_{to}}{dt} = S_{to} G_t \alpha_{to} \tau_p - S_{to} \sigma_s F_{top}\left(T_{to}^4 - T_p^4\right) - S_{to} h_{to}\left(T_{to} - T_a\right) - \\ S_{to} \sigma_s F_{tob}\left(T_{to}^4 - T_b^4\right) \tag{2}$$

- Heat transfer on the drying air:

$$\overset{*}{m}_a C_a (T_{as} - T_{ae}) = -S_p h_{ci}(T_a - T_p) - S_b h_b (T_a - T_b) - S_{to} h_{to} (T_a - T_{to}) - \\ m_o (1-\varepsilon)(L_{he} + E_b) N \tag{3}$$

- Heat transfer on the wood:

$$m_b C_b \frac{dT_b}{dt} = -S_b F_{bto} \sigma_s \left(\boldsymbol{T}_b^4 - \boldsymbol{T}_{to}^4\right) - S_b h_b (T_b - T_a) - \\ \lambda_b S_b \frac{dT_b}{dx} + m_o (1-\varepsilon)(L_{he} + E_b) N \tag{4}$$

-Mass transfer on the wood [13]:

$$\frac{dX}{dt} = -N(1-\varepsilon) \tag{5}$$

$$N(X) = \frac{n(X - X_{eq})^2}{\sigma(X_o - X_{eq})} \left(\frac{X_o - X}{X - X_{eq}}\right)^{\frac{n-1}{n}} \tag{6}$$

- Mass transfer on the air drying [11,12]**:**

$$\rho_a V_s \frac{dY_a}{dt} + \rho_o V_o \frac{dX}{dt} + \overset{*}{m}_a (Y_a - Y_{ae}) = 0 \tag{7}$$

-Temperature of the vault of heaven [14]:

$$T_{ciel} = 0.0552 T_{ab}{}^{1.5} \tag{8}$$

-Relative humidity of the air drying [15]:

$$HR = \frac{P_a}{P_{vsat}} \frac{Ya}{0.622 + Ya} \tag{9}$$

### 4.2. Convective thermal exchange coefficients

-Between ambient air and the exterior of wall of the dryer Mc Adams relation [14] has been used. It is given by:

$$h_{vv} = 5.67 + 3.86V_v \qquad (10)$$

- Between drying air and the interior wall of the dryer

The Nusselt's number is used [16] and is given by:

$$Nu = 0.27(Gr.\mathrm{Pr})^{0.25} \qquad (11)$$

$$h_{ci} = \frac{\lambda Nu}{L} \qquad (12)$$

-Between drying air and sheet-metal (black body)

The Nusselt's number used on each face is given below where hydraulic diameter is the radius [16].

$$Nu = 0.480(Gr.\mathrm{Pr})^{0.25} \qquad (13)$$

$$h_{to} = \frac{Nu\lambda}{R} \qquad (14)$$

-Between drying air and the samples

The Nusselt's number is given by the formula [16]:

$$Nu = 0.54(Gr.\mathrm{Pr})^{0.25} \qquad (15)$$

$$h_b = \frac{\lambda Nu}{L_b} \qquad (16)$$

### 4.3. Method of the resolution of the equations of transfer

Numerical method that we have used is implicit finite differences because all unknown parameters are given in the time $t + \Delta t$. For example, variation of wood water content is given by the relation (17) who comes from relation (5).

$$\Delta X = -N(1-\varepsilon)\Delta t \qquad (17)$$

## 5. Results and Discussion

Characteristics of wood are given in the literature [13]. Experiments are doing during the month of March in the town of Yaoundé-Cameroon (Latitude: 3.87°N; Longitude: 11.52°E; Altitude: 720m [17]). For this month, literature indicates that irradiation density average is $G_t$=215W/m$^2$ [18].

We note a same evolution between theoretical and experimental values. Drying time is 600h to pass water content of our wood at 27% to 17% (fig.2-a). This drying time is important compared at the time used in artificial drying to obtain same final water content. Difference between experimental and theoretical values (absolute error) is evaluated at $\pm 6.03\%$. Many reasons can to explain this disagreement. We can note a difficulty to determine with exactitude initial conditions of wood samples and the components of the dryer, a bad estimation of the solar irradiation of the site because, this last value is function of the hour and the day. Also, estimation of the values of modified quasi stationary model that varied with water content. During all manipulations, a door of dryer is opened for to take measures and consequently, exchange between exterior and interior air are doing. In the modeling, this behavior is not taking account. In whole, average differences that we obtained and same evolution between theoretical and experiment, our modeling can to be used for to analyze a behavior of components of the dryer. Thus, this modeling can to be used for to research an optimal functioning of the dryer through a study of sensibility of many parameters. Figure 2-b presents wall temperature evolution, sheet-metal temperature and the interior air of the dryer. Average interior air temperature quickly increases that sheet-metal temperature and wood temperature. Thus, interior air is quickly saturated with water vapor in proximity of the sheet-metal and the wood [19]. Initial temperature of the wall is equal at the ground temperature. Initial temperature of interior air and temperature of sheet-metal are taking equal at the average air exterior of the Yaounde town during a month of experiment. We note a quickly evolution during the ten firsts hours of drying. Air temperature is most important during the seventy firsts hours of drying. Thus, a quickly extraction of water in the wood is favourable. A decrease of air temperature after the ten firsts hours of drying coincided with the increase of wood temperature because air absorbs humidity which evaporate of wood [20]. The wood temperature, the air temperature and the sheet-metal temperature have a same limit temperature (34°C) showed that a stability temperature of the component of dryer is obtained after 150 hours of the drying. The wall temperature is the most weak because it exchanges a heat with the air exterior. Figure 3 shows a good approximation of the evolution of the water content in dry basis of the wood by our model when initial temperature of drying air is taking equal at 24.4°C, then in proximate of the ground temperature of the town of Yaoundé in the month (March) of the experiment(24°C) [17,21,22]. In these conditions, average relative error between experiment and theoretical values is ±0.812%. This result shows a very importance of initial conditions on all the evolution of the solar dryer. It is primordial to define good initial conditions before simulate a solar dryer.

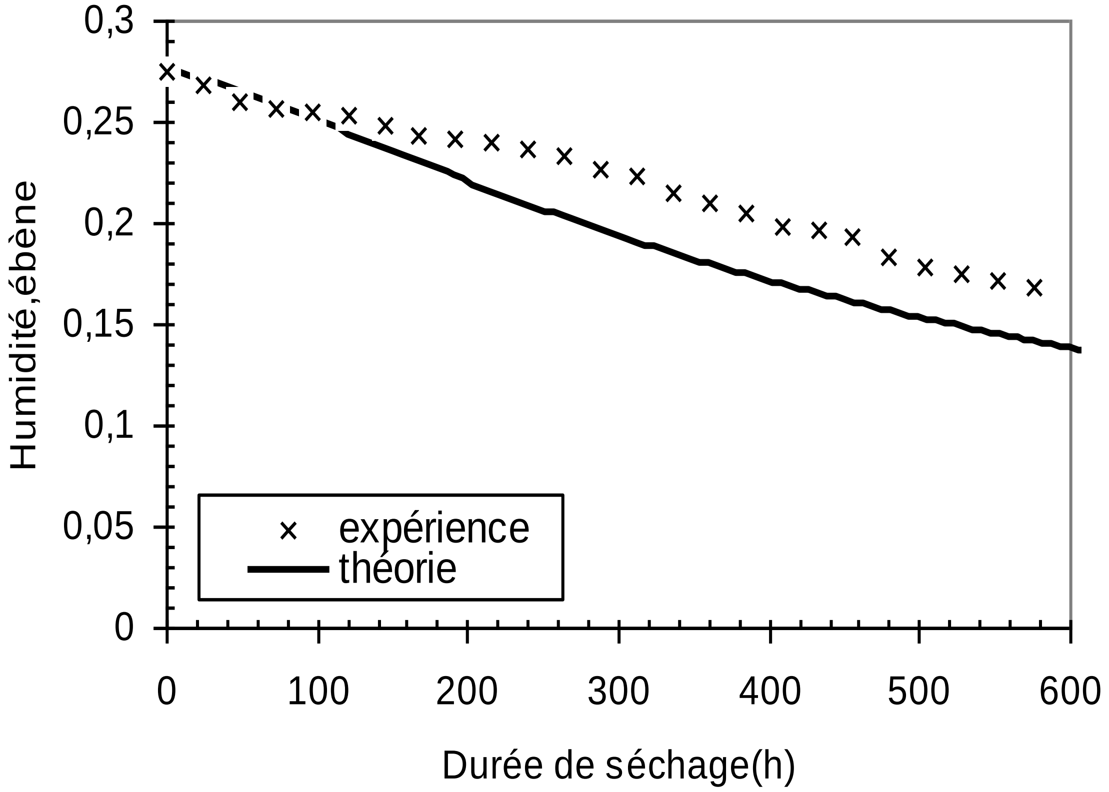


**Fig.2.a. Water content (kg/kg) versus drying time (h)**

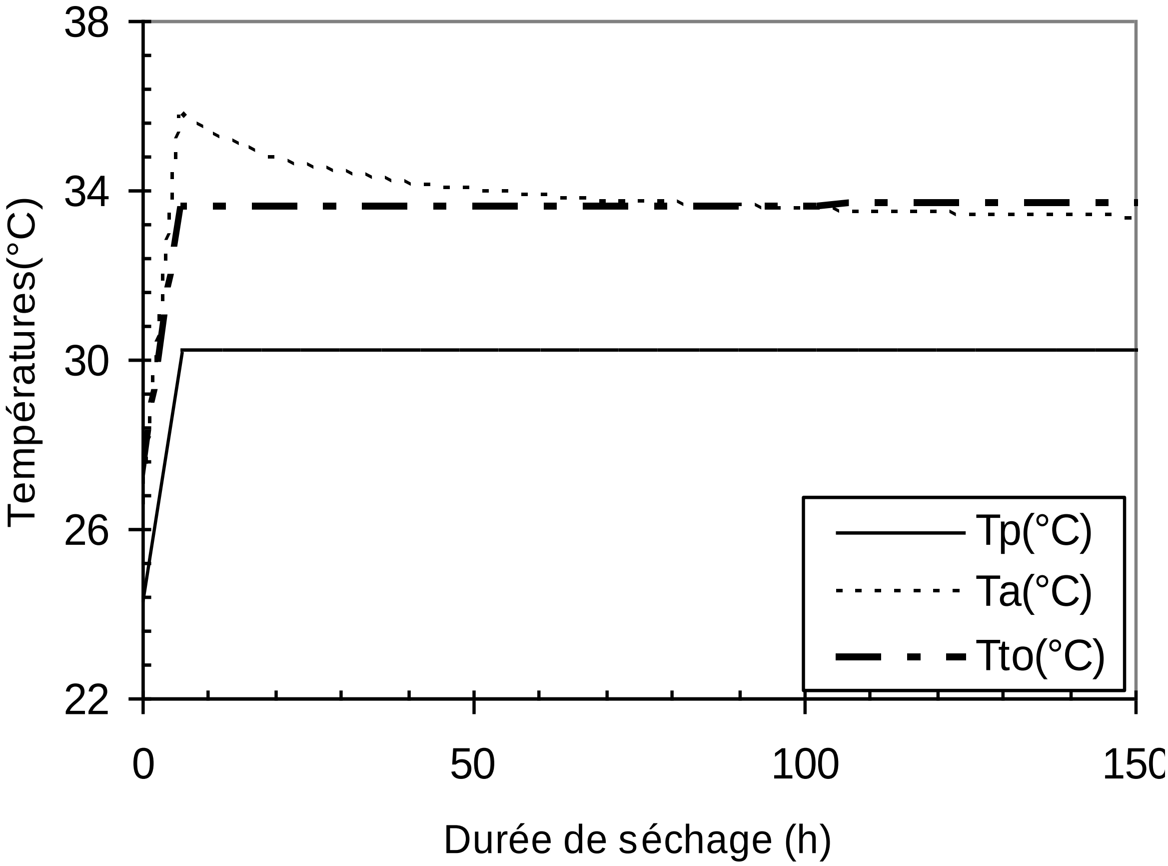


**Fig.2.b. Daily average temperature (°C) versus drying time (h)**

**Fig.2.** Comparative evolutions of theoretical and experimental water content and temperature of the components of the dryer with the drying time

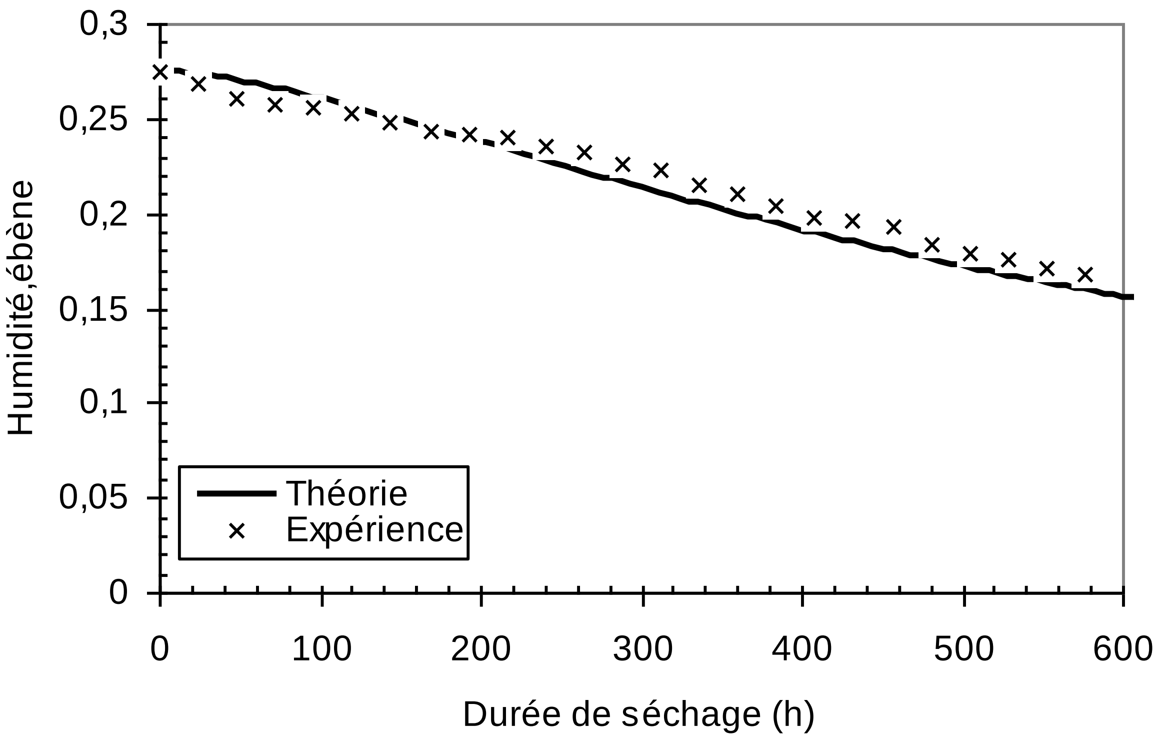


**Fig.3. Comparative evolutions of theoretical and experimental water content of the wood, $T_a$=24.4°C**

## 6. Conclusion

The present model permits to estimate the evolutions of the temperatures of the components of the solar dryer and also of the water content of wood. A good estimation of initial values of the temperature and humidity of the components of the dryer gives a good estimation of evolutions of these parameters during all the drying process. Final values of the water content are important. For this reason, it is important to envisage a construction of forced convective solar dryer with exchange air between exterior and interior.

## Nomenclature

C: Specific mass heating (J/(kg.K))

$E_b$: Heat of desorption of the bound water (J/kg)

$G_t$ : Solar irradiation (W/m$^2$)

HR: Relative humidity of the air (-)

h :Thermal transfer coefficient (W/(m$^2$.K))

L, R: Characteristic diameter (m)

$L_{he}$: Latent heat of vaporization (J/kg)

$\dot{m}$: Mass kinetic (kg/s)

m: Mass (kg)

N: Drying kinetic (kg/(kg.s))

P: Pressure (Pa)

S: Surface (m$^2$)

T: Temperature (°C)

t : Drying time (s)

V : Volume (m$^3$)

$V_v$: Air kinetic (m/s)

x: X-axis of the thickness (m)

X: Water content (kg/kg)

Ya: Air humidity (kg/kg)

*Greek Symbols*

$\alpha$ : Absorptance coefficient(-)
$\rho$: Density (kg/m$^3$)
$\varepsilon$: Porosity of the wood (-)
$\varepsilon_v$ : Emissivity of the component v (-)
$\lambda$: Thermal conductivity (W/(kg.K))
$\sigma$: Second parameter of modified Quasi stationary model (-)
$\sigma_s$ : Stefan Boltzmann's constant (5.67x10$^{-8}$W/(m$^2$K$^4$))
$\tau$ : Transmittance coefficient (-)

*Subscripts*

a: Air

p: Wall

vsat: Saturated vapor

eq :Equilibrium

o :Initial or Anhydrous

b, to : (respectively)Wood and black body

i,e : (respectively) interior and exterior

*Non-dimensional Numbers*

Gr: Grandshopp's number

Nu: Nusselt's number

n: First parameter of modified Quasi stationary model

Pr : Prandtl's number

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