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MODELING OF PROFILE TEMPERATURE AND KINETICS OF COFFEE BEANS DRYING USING SOLAR DRYER ICARO IMPROVED

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ABSTRAT

In this article, we realized the modified Icaro dryer to dry coffee. The design of this dryer is inspired by previous work; which showed that coffees from Africa have an earthy and moldy taste [1]. This is evident from the fact that in these areas coffee is dried on clay or cemented areas in the open air. This technique will allow coffee growers to improve the succulence of coffee. The modeling of the temperature allowed us to obtain a uniform value of 54 ° C. Thus, setting the model coefficients a and b, depending on the product mass, the height and the drying time [2], reduces the coffee water content from 70% to 12.5%. Among the models of Newton, Page and Henderson Pabis, the logarithmic model fits better with the experimental measures of share, the choice based on the highest R^2 (0.984), Chi-2 and lower ESM. In addition, the calculations of the constants of the logarithmic model allowed us to retain it from the others.

KEY WORDS: Solar dryer, moisture content, model logarithmic

I. INTRODUCTION

Coffee is a product that undergoes many treatments before being consumed. The one from Africa has a soiled taste, due to the persistence of traditional drying [1]. Drying is a crucial phase in processing, since the quality and price of grains depends on the technique used. The proposal of this new coffee drying technique allows African coffee growers to improve the taste of coffee. It significantly reduces the drying time experienced by the traditional method, from 21 days to less than a week, according to our expected results. Our contribution was to take into account the massless aspect of temperature modeling which was not considered by Kuitche et al. Thus, the use of a solar dryer based on the Icaro model [3], brings the renovation to the drying technique. The parameterization of coefficients of model a and b, favors the reduction of the water content from 70% to 12.5%. This is a better guarantee for storing coffee after drying. Results are obtained by applying the Luickov equations and drying kinetics through the logarithmic model [4]. Several types of solar coffee dryers have been developed to find an answer to the problems mentioned among which ours. In order to find the right model for coffee drying, we realized that the work of N. Venkatachalapathy et al [4] showed that it is possible to model the water content of coffee by the logarithmic model. Finally, the study of the temperature profile and the drying kinetics of the coffee will enable us to achieve the objective four thesis work.

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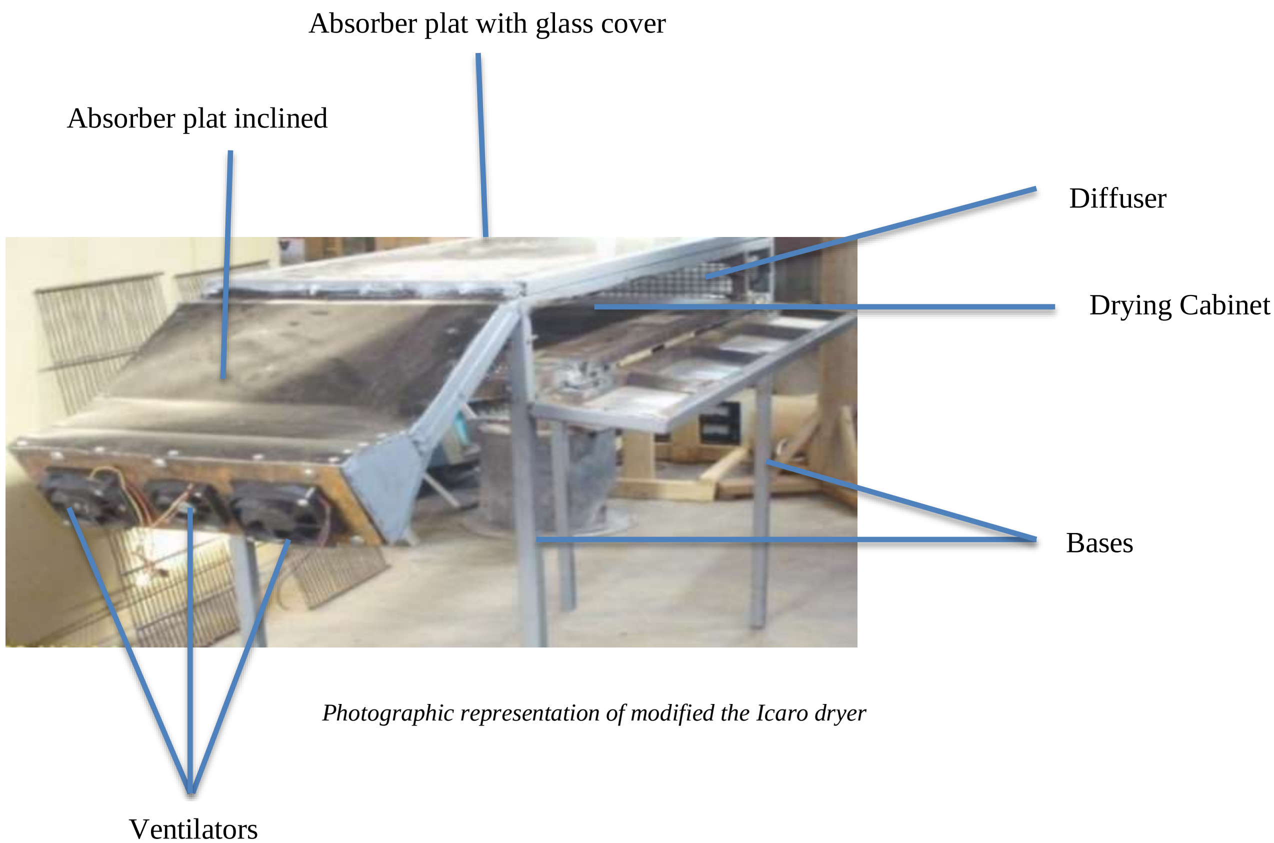
II. MATERIEL AND METHODS

II.1 Material of drying

In order to carry out this work, we designed a dryer of the Icaro modified model with forced convection [3]. This dryer is composed of an inclined plane sensor, a horizontal plane sensor and the drying cabin (Figure 1). The water contents of the fresh product as dry are measured using a Dicky-john moisture meter. The temperature is measured using type K thermocouples. The masses of the samples are measured using a precision electronic balance with a maximum load of 2 kg. The reading accuracy on the measurements is 0.01g. The figure below shows the device.

Figure 1:



Photographic representation of modified the Icaro dryer

II.1.1 Description of the vegetable material

The Central African Republic only cultivates the variety Robusta (Coffea Canephora), and therefore our study focuses on this variety. Of course, Robusta grows in the tropics around the equator [1]. Harvesting and drying are from November to February. The frequently used drying method is open air display. The harvesting method used by Central African coffee growers is "striping". The fresh water content is 70%, the recommended final content 12.5% and the caffeine content 2.32%, recommended in the literature. Its seed is rounded and smaller than that of Arabica. The image below shows the example of drying by the dry route (drying in the sun).

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Figure2:

Open sun drying

II.1 .1.1 Measure various sizes

We calculated the predicted temperature using the parameterization of model coefficients a and b as a function of product mass, distance and drying time. This temperature calculation has been entered and coded in a Matlab and Excel environment. As for the measurement of mass, it is done at the beginning and at the end of the operation. The relative humidity of the ambient air is measured directly using a mini weather station Vantage Pro 2. The air flow rate in the drying compartment is measured by placing the wired potentiometer probe hot in the drying cabin. The mass is distributed equitably over the racks by keeping the other input parameters constant.

II.1.2 Drying Kinetics and Mathematical Modeling

Four empirical models were used to model drying kinetics. These are the models of Newton, Handerson and Pabis, Page and Logarithm (Table 1). From the results obtained, the Logarithmic model is considered the best to describe the behavior of coffee drying whatever the drying method used. The calculations of the correlation coefficient values, of the average systematic error and the specific constants recorded in Table 2 justify the choice of the model.
Table

Table1: Empirical thin-layer models considered in this paper

Model n°.	Model Name	Equations	References
I	Newton	$MR = exp(-k.t)$	Ayenus and al. [5]
II	Handerson and Padis	$MR = a.exp(-k.t)$	Akpinar and al. [6]
III	Page	$MR = exp(-k.t^n)$	Paulo Carteri Coradi and al. [7]
IV	Logarithmic	$MR = a.exp(-k.t) + c$	N.Venkatachalapathy [4]

II.2.2 Expression of drying temperature compared to the absorber

The temperature of drying is calculated using the expression developed by A. Kuitche et al. [2].
The formulas are given by the expressions without the mass and with mass following:

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Without mass:

$$a = 27 - 0.99 \times \left(\frac{H}{100000}\right) - 0.0123 \times H - \frac{5}{t} \quad (1)$$

$$b = 0.0123 \times H \quad (2)$$

$$T = a \times (2 - \exp(-b \times t)) \quad (3)$$

With the mass:

$$a = 27 - 0.99 \times \left(\frac{M \times H}{100000}\right) - 0.0123 \times H - \frac{5}{t} \quad (4)$$

$$b = 0.0123 \times \frac{H}{M} \quad (5)$$

$$T = a \times (2 - \exp(-b \times t) \quad (6)$$

Where;
T: predicted temperature (C)
t: time put in the drier (min)
a: coefficient of the ambient one
b: opposite of the constant of time
H: outdistance to absorb it with the trays (m)
M: mass product to be dried (kg)

Statistical validation of the selected models

These calculations will have to admit that the coefficient of correlation either high, the statistical parameter used to improve Chi-2 smoothing (X^2) or reduced and minimal and finally the Average Systematic Error (ESM) must be minimal. N and Z are the numbers of observations and constants. Equations (7) and (8) are indicators for evaluation of the drying models

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp.i} - MR_{pre})^2}{N-z} \quad (7)$$

Regression analysis was performed. The coefficient of determination (R^2) and root mean square error (RMSE) were used in this study to evaluate the goodness of fit. These parameters can be calculated by using the following equations:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp.i} - MR_{exp.i})^2} \quad (8)$$

II.2.3 Expression of the air flow (D) and mass to remove M_e

To find the Mass of air needed for drying:

$$D = \frac{M}{t_s} \quad (9)$$

Where;
D: air flow (Kg/h)
t_s : duration of the operation of drying (h)

To find the amount of moisture in kilogram to be removed from the product was calculated using the following equation [8]:

$$M_e = M_i \frac{(MR_i - MR_f)}{(100 - MR_f)} \quad (10)$$

Where;
M_i: Initial mass of coffee being dried (kg)
MR_i: Initial moisture content (%)
MR_f: Final moisture content (%)

Experimental Drying process
The air flow is calculated according to the measurements taken at the entry of the sensor. The heating of the device is of the fluctuation the sunning. The temperature is measured thanks to the infra-red thermometer. The coffee cherries laid out on the trays horizontally in the direction of the hot air flow. A whole of tests (12 observations) is envisaged initially in the enclosure of drying without trays, then in the same enclosure with empty trays and finally on the coffees for the values of equitable mass de1kg on average by tray.

Experimental process
This consists in making directly dry coffee cherry fresh collected before separating into only once the grain from all its envelopes. Like our drying is done in thin layer, then the thickness of our heap of drying is between 3cm to 5 cm on average [1].

III. RESULTS AND DISCUSSION

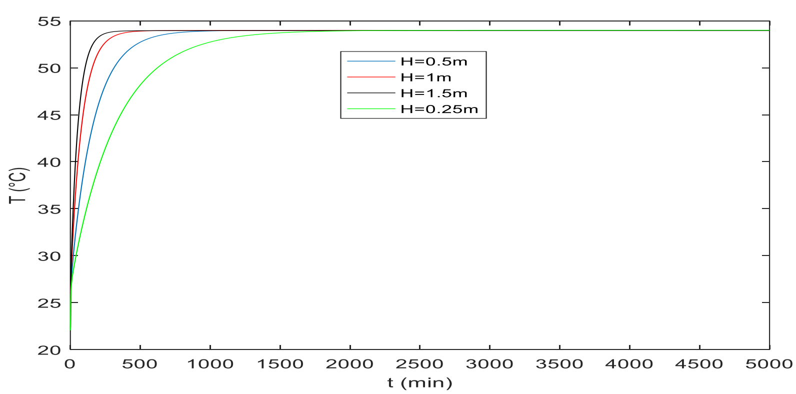
This work of simulation of temperature and water content was validated with experimental results of Kuitche and al. [2] and also compared with our experimental results.

III.1 Effect of distance absorber to the tray on the temperature

This section analyze the temperature for four case studies, the case studies are varying height of sun. Simulations (experiments) were carried out with four different heights of 0.25, 0.5, 1 and 1.5m, to investigate the effect of distance on temperature

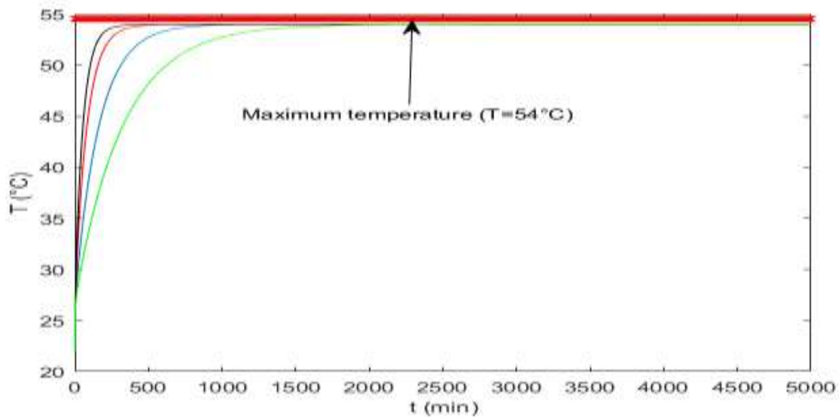
Figure 3 shows the influence of the distance to the heat source on the temperature. We notice that the temperature quickly reached its maximum when the tray is near to the absorber. The temperature curves have the same pace. This result agrees with the work completed by A. Kuitche et al. [2].

Figure 3:



The effect of distances H on the temperature

Figure 4:



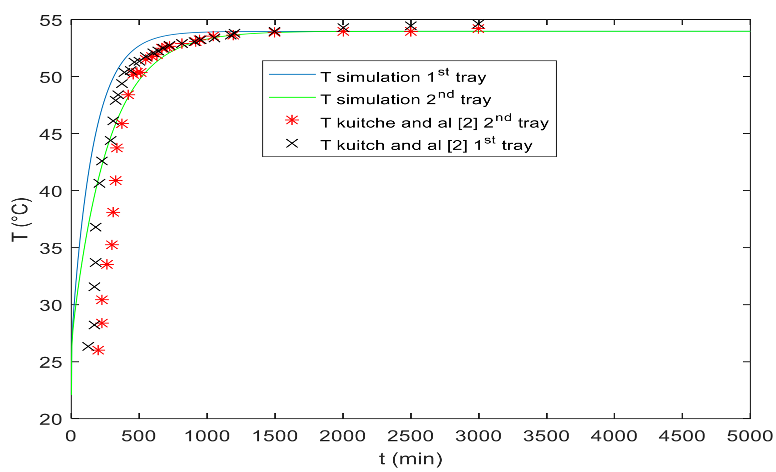
Curves at various distances (H) and liming temperature (T=54°C)

Figure 4 indicates the maximum temperature for the simulation of the various distances compared to the absorber. These two figures enable us to choose the distance to the heat source which we need for our making. This result gives the same profile of temperature that that obtained by Inci Turk et al [9]. While studying Modeling of drying kinetic of singe apricot.

III.1.1 Validation of the model

The results of the digital simulation were validated with work of A. Kuitche et al [2]. These results are given by figure 5.The figure shows a good agreement between our results and the results of Kuitche.

Figure 5:



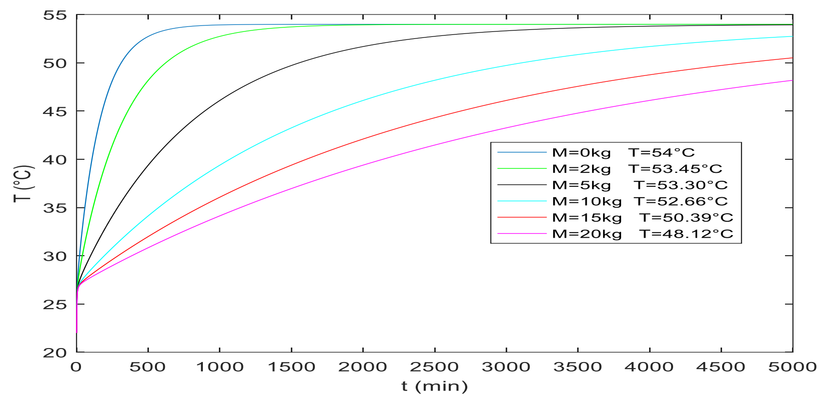
Comparison of the results

The comparison between our numerical results and the experimental results Kuitche [2] are presented on figure 5, for a position of distances H=0,35m and H=0.5m, the profile show a good agreement between the trays.

III.1.1.1 Effect of mass on temperature

In this section different values of mass of (coffee) were considered, in order to investigate the effect of mass on the temperature.

Figure 6:

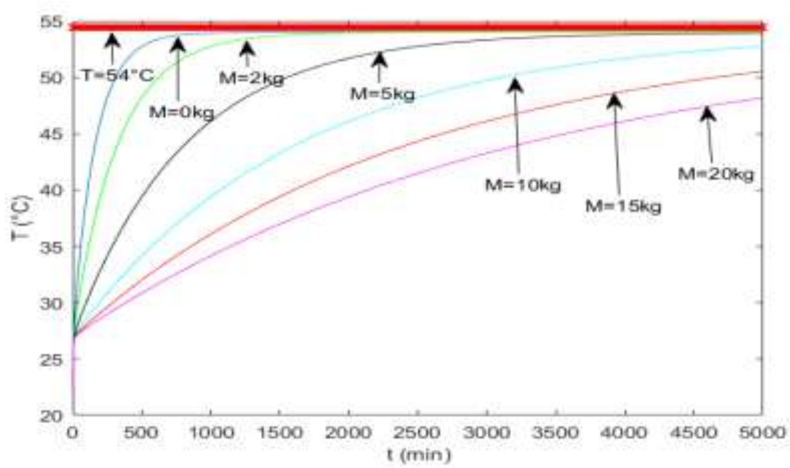


Temperature curves of the various masses

Figure 6 shows the influence of the mass of coffee on the temperature. One notices that the more the mass increases, the more the temperature takes time for reaching his level of balance.

That shows that the change of the temperature charges some is proportional to the thickness of the product which causes strength to the temperature. These curves show us that one charges some observes a very light variation in temperature according to the position of the thermocouples on the tray; this variation not exceeding 6°C, is observed center towards the end of the tray and 0 kg to 20 kg. This highlights the uniformity of the temperature at the surface of a tray charged with coffee. This result enabled us to choose the mode of provision of the thermocouples in the drier during the tests in load.

Figure 7:

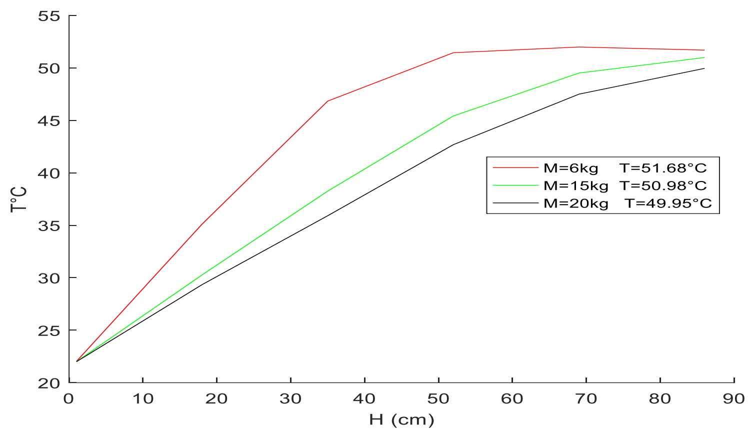


Comparative curves of temperatures with the masses

Figure 7 also presents the results of the temperature as function of time from different masses (2 kg, 5 kg, 10 kg 15 kg and 20 kg) of cherry of the coffee. This figure indicates that the temperature of balance as function of masses. It should be note that, at the end of the drying process, all trays have different temperature.

The temperature between the trays decrease as the mass of the product increased and the position of the tray compared to the absorber. Hence, increasing the mass and volume of product (coffee) affects significantly the process in phase 1 which consist of the temperature setting of the product, the mass loading and the height of drying accentuated the change in temperature inside of drying device. Which temperature gradient is responsible for heterogeneity for coffee?

Figure 8:



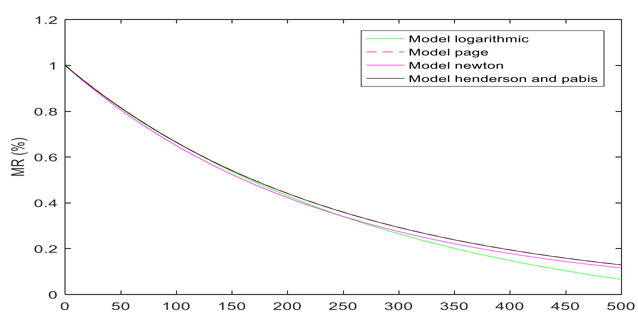
Variation in the temperature interior of the dryer for various masses

Figure 8 shows the change of the temperature inside the drier for different values of mass. the figure shows that maximum temperature for 6 kg, 15kg and 20kg are 51.68°, 50.98° and 49.95°, respectively. These results illustrate that the vaporization of the water in a coffee is proportional to coffee thickness and the position of the product in the dryer. in order to evaluate the moisture, a test with temperature obtained for different positions of product in the dryer.

III.1.1.2 Determination of moisture content of four models

Four models were used in simulation, in order to investigate moisture content evolution. Figure 9 presents the profile of the moisture content as function of time for different models used.

Figure 9:



Variation of moisture ratio with time at different model

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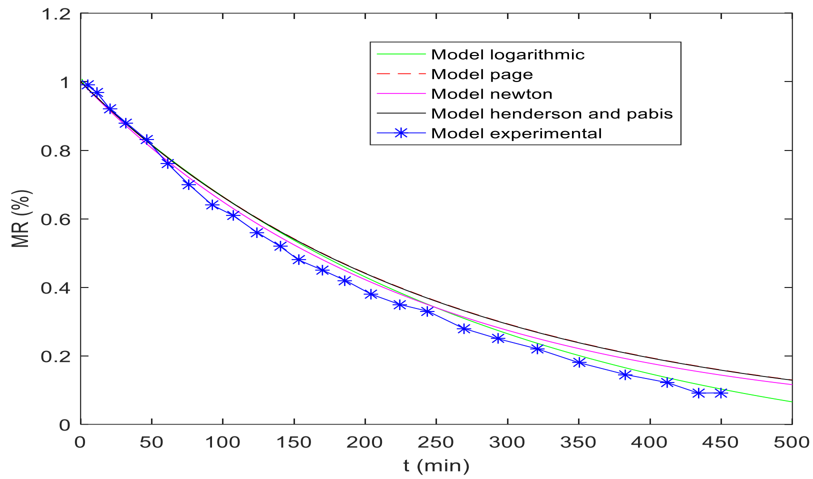
From the figure 9, the moisture content of the sample coffee decreases gradually and requires a large time to achieve 12.5%. The potentiometer was set to 1.5m/s of air velocity, in order to obtain the temperature of 54°C. Figure 8 also shows that for different model used, the profile of moisture contents have same trend. Moisture content of the four models studied profiles here resembles that obtained by Paulo Carteri Coradi et al. [7] on Coffee Cherries Drying Process and the Influence of environment Relative Humidity in the mathematical modeling, Moisture content, and Enthalpy of Vaporization.

III.1.2.2 Comparison of models theoretical and the experimental

The comparative study between the numerical and experimental results makes enable to retain a model among the others.

Figure 10:



Comparison of moisture content for four models used with experimental data

In order to select a suitable models for simulation, four different models including logarithmic. Page, Newton and Henderson and Pabis were simulated. Figure 9 presents results from different models; the results are analyzed in comparison with experimental result, for 20 kg of coffee. From this figure, all models have same trend and the moisture contents decrease with increase of time. However, results from the logarithmic model are closed to the experimental comparing with the results from other models which present small variation. This is due to the weather parameters and the specificity of the matter like temperature, air velocity, relative and absolute humidity.
However, Table 3 presents the coefficient of models used in simulation. The values of the parameters obtained by the Logarithmic model from 0 to 5000 minutes for a mass of 2kg are appropriate to the aim of this work. It should be notice that the computed values, shows the importance of the choice of the model used because these results obey the same principles of the values recorded in previous work. The logarithmic model, with R^2 of 0.984 and $\chi^2$of 6.4.10 $^{-3}$ shows the high value of R^2 and small value of χ compare to other models. These values show well that the coefficient of correlation is high and that chi-square is reduced and minimal hence attesting the consistency of the selected logarithmic model. The simulation used logarithmic model can be regarded as satisfactory for the profile characteristic (Figure 10) of the coffee in extended an enough range of the temperature and air velocity.

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From these results, two principals remarks should be draws: The absence of the phase of temperature setting constant and that. This result is in conformity with the literature [8]; several researchers announced the disappearance of the period of temperature setting during the drying of the sheets and also the absence of constant phase in many cases when they are the crop products. The presence of phase II marked by the decreasing pace (phase of deceleration), shows that our product behaves like these crop products. The regression results presented in Table 2 show that Page model gave the lowest value of RSME, chi-square and χ^2 compared to the other three models. It also has the highest value of R^2 and thus it is the model that best fit the drying of coffee.

Table

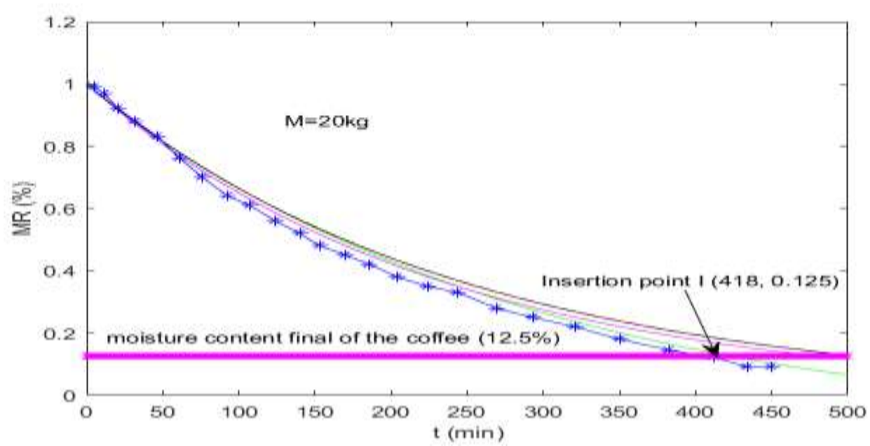
Table 2: Coefficient of determination, Root mean square, χ^2 and the constant values for different equations

Model	Coefficient of correlation R^2	X^2	RSME	Air flow for 2Kg/h	Mass water to remove (kg) water
Newton	0.958	0.011	0.09	0.16	1.32
Henderson and Padis	0.955	0.007	0.07		
Page	0.975	0.0036	0.072		
logarithmic	0.984	0.0064	0.06		

III.2.2.2 Effect of the mass 20kg on moisture content with drying time

The addition of 20kg shows the effect of the increase in the mass on the temperature according to time.

Figure 11:



Comparison of the moisture content predicted with moisture content limiting (MR=12.5)

Figure 11 presents a perfect agreement between the curve of the moisture content experimental and the moisture content reduced of the model logarithmic curve. The curve presenting the moisture contents predicted according to the time of drying are followed by models consigned in table 3.

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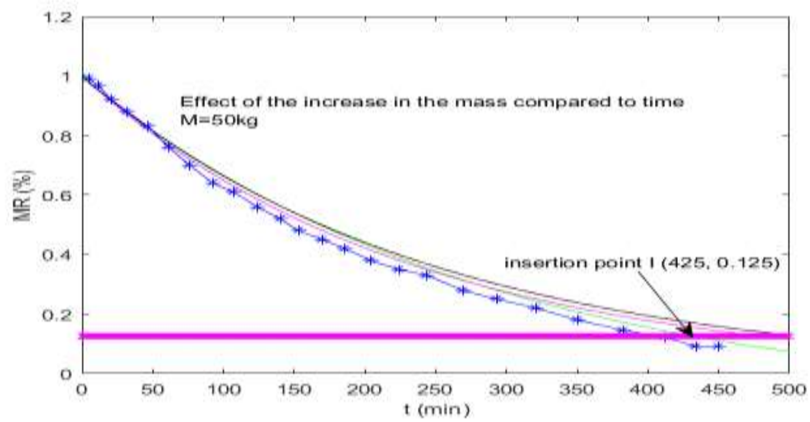
III.2.2.2 Effect of mass 50kg on moisture content with drying time

The effect of the mass of 50kg on the temperature influences more over time than the mass of 20kg.

Figure 12:



Curve of the moisture content with M=50Kg

Figure 12 shows the comparison of the profile of the model logarithmic with experimental. Figure 10 illustrate that for coffee 20kg, the profile of the model logarithmic and experimental cross with 418min. On the other hand, figure 11 shows that for 50kg of coffee, the two curves have an f intersection at 425min. this is justified by the effect of the increasing in the mass on the moisture content according to time. In addition, figure 12 shows that the Newton, Page, and Henderson and pabis move away more and more from the experimental model. Thus, from this results can deduce that the model logarithmic model agrees better with the experiment.

III.2.2.3 Recapitulation of the various parameters of the model selected

Table

Table 3: Values of constants of the selected models

Model	a	k	c	n
Newton		0,00409		
Henderson et Pabis		0,0041		
Page		0,00431		1,0001
Logarithmic	1,1274	0,0031	-0,1780	

The values of the parameters obtained by the Logarithmic model in the time interval from 0 to 5000 minutes for a mass of 2kg are suitable for the intended purpose. Note that our calculated values, we approve the importance of the choice of model used because they follow the same principles of values found in previous work. The coefficients of each drying model are presented in Table 3. The logarithmic model showed a good correlation with the experimental curves with an R^2 of 0.984 and χ^2 of $6.4.10^{-3}$. These values show that the correlation coefficient is high and that chi-square is reduced and minimal, thus attesting to the consistency of the logarithmic model chosen. The simulation established here by the logarithmic model can be considered satisfactory for the coffee characteristic curve in a fairly wide range of temperature and air velocity.

The predicted temperature curves with and without mass reach an equilibrium temperature of 54 ° C which is within

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the expected temperature range (50°C to 60 ° C). This allows us to appreciate the choice of our mathematical modeling. However, we observe a very presentable slope for the temperature curve with mass compared to that without mass. In addition, the temperature equilibrium curve without mass appears early at 713 min compared to that with the mass which appears later around 1470 min. This is because the product has a water content that requires warming up for the thermodynamic equilibrium to be established. Moreover, we say that the value of the equilibrium temperature obtained according to our result, shows that the dimensioning related to the manufacture of our device was well respected. These aspects mentioned, we notice the influence of the mass on drying air. The predicted curve of the water content of the coffee facing the experimental curve gives us a good approximation for the logarithmic model, however, we note a small difference for the other models. This comes from meteorological parameters (temperature, air velocity, relative and absolute humidity) and specific characteristics such as hygroscopy, porosity and conductivity of coffee beans. The temperature fluctuates around the value of 60 ° C, while the modeling is based on a constant temperature. The flow of air in the enclosure encounters obstacles, resulting in point variations in speed that are not taken into account in the modeling. The relative and absolute humidity of the mass of the coffee to be dried are in the arrangement of the grains on the racks. This confers a more or less variable density; moreover, the water content is specific to each grain while the modeling starts from a constant density mass with a constant and uniform water content.

IV. CONCLUSION

The behavior of coffee bean drying was studied in a hot air dryer at a temperature of between 50°C to 60 ° C and an air speed of 1.5 ms-1. The numerical study using the Matlab software to simulate the temperature, allowed us to obtain a temperature around 54 ° C. This result is very encouraging and deserves to be applied to certain products. This allows us to consider this mathematical modeling of temperature following the application of the parameterization of the coefficients a and b of our model (equation1 and 2), on the one hand. On the other hand, among the statistical models studied, the logarithmic model showed a good correlation with the experimental curves with an R^2 of 0.984. Therefore, the logarithmic equation is chosen to model the coffee drying curves. The logarithmic model allows a satisfactory adjustment of the experimental data (R^2 = 0.984, χ^2 = 0.0064 and RESM = 0.06).

V. ACKNOWLEDGEMENTS

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