Tema A2a Termofluidos: Cinética de secado

"Guava thin layer drying kinetics for an indirect solar dryer"

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RESUMEN

La cinética de secado para la guayaba madura e inmadura se estudia para un secador solar indirecto. Las temperaturas de secado fueron consideradas entre 33 a 61 °C al interior de la cámara de secado. Se examinó el comportamiento Fick del proceso de secado, observando un efecto significativo relacionado con el grado de maduración de la fruta. Los coeficientes de difusión efectivos (D_f) fueron de $3.161x10^{-10}$ m^2/s y $3.038x10^{-10}$ m^2/s, para la guayaba madura e inmadura, respectivamente. El secado solar es suficiente como un procesamiento postcosecha alternativo que permite la formulación de nuevos productos, como en tés o en la formulación de mezclas para bebidas mexicanas tradicionales (el llamado "ponche").

Palabras Clave: Cinética de secado, Secado solar, Difusividad efectiva, Guayaba.

ABSTRACT

Drying kinetics for ripe and unripe Guava are studied for an indirect solar dryer. Drying Temperatures were considered between 33 to 61 °C inside drying chamber. The Fick behavior of the drying process was examinated, observing a significant effect related to the ripeness degree of the fruit. The effective diffusion coefficients (D_f) were $3.161x10^{-10}$ m^2/s and $3.038x10^{-10}$ m^2/s, for the ripe and unripe Guava, respectively. Solar drying is sough as an alternative post-harvest processing allowing the formulation of new products, such as in teas or in formulating mixtures for traditional Mexican beverages (so-called "ponche").

Keywords: Drying kinetics, Solar dryer, Effective diffusivity, Guava.

Nomenclature

D_f	effective diffusion coefficient
IM	Maturity index
L	half thickness of slab (mm)
M	Moisture content at a specific time
M_e	equilibrium moisture content
M_o	Initial moisture content
T	Time (min)
M/M_o	Weight loss

1. Introduction

Guava (*Psidium guajava L.*) is a tropical fruits belong to the Myrtaceae´s family coming from tropical and subtropical countries. The fruit has between 3 to 10 centimeters of diameter and its color varies green to yellowish depen about specie and degree maturation. The inner layer is softer, juicy and creamy, and contain large amount of woody and hard seeds. This fruis is widely consumed to global level due nutritional propierties, such as: low in carbohydrates, fats, proteins and high amount of vitamin C and fiber [1]. When the fruits are harvested, its metabolic activity continues due its respiratory behavior, therefoere, the physicochemical, sensory and nutritionals properties change and deteriorate the fruit as the maturation process advances [2].

Proper drying of *Guava* enhances good appearance, original taste and maintains nutritional quality. Conventional based dryers are being used by farmers for drying which are energy intensive. In this context, renewable energy based solar dryer is considered as an alternative to conventional drying to reduce drying cost and environmental sustainability. Modeling of the drying process is one of the most important aspects of drying technology. The thin layer drying model has been found to be most suitable for characterizing the parameters. For this reason, several researches on the mathematical modeling and experimental studies had been developed about layer drying processes of various agricultural products [3-6]. Thus, others have found behavior of ripe jackfruit and its value of effective moisture diffusivity, with a maximum and minimum diffusivity of $4.56x10^{-10}$ m²/s and $1.264x10^{-10}$ m²/s at 80°C and 50°C, respectively [7]. While, the cucumber convective drying, presents a diffusion coefficient between 2.55 to $7.29x10^{-10}$ m^2/s [8]. Some researchs has presented a comprehensive review of modeling thin layer drying of fruits and vegetables with particular focus on theories, models, and applications thinlayer. Also, shows the effective moisture diffusivity of fruits and vegetables in the range 10^{-12} to 10^{-6} m^2/s. In addition, about 80 % of the diffusivity values are in the dominant region between values 10^{-11} to 10^{-8} m^2/s [9]. Other authors, has presented mathematical models of thin layer drying kinetics with other equipments such as: used microwave equipment to differents power level (200-900 W) at 50°C of temperature. They have obtained diffusivity coeffcient values between 5.46 to $39.63x10^{-8}$ m^2/s [10]. Some has presented different cases such as: the drying kinetic behaviour of crumb rubber. The authors present an effective diffusivity $5.243x10^{-9}$ m^2/s in a vacuum oven at 90°C [11].

For this, is necessary to implement a conservation method. The drying is the most applied to improve food stability because decrease of water amount, microbilogical activity, and minimizes physical and chemical changes during storage [12], with drying times short, low process temperature, low energy consumption and minimum damage to the product [13]. Though the primary objective of food drying is preservation, depending on the drying mechanisms, the raw material may end having significant variation in product quality.

An alternative to the drying process of fruits and vegetables is through renewable energy sources such as solar irradiation. In many parts of the world the sun provides radiation that allows one to take advantage of it approximately 12 h during the day. Solar energy for drying applications is preferable because it is abundant, free, inexhaustible and non-polluting [14].

Here the drying kinetics of the *Guava* fruit are investigated, seeking to establish a first-principles foundation for the modeling and subsequent scaling for indirect solar dryers design.

2. Materials and methods

Forthy ripe and unripe samples of *Guava* were recolected from Tlaltizapan Morelos, Mexico. With latitude and longitude of 18.6833 and -99.1167, respectively. The samples where collected during the 2016 Harvest. The months of october and november of each year are considering the best harvest time. The products were desinfected, washed and dried with absorbent paper before being stored in a freezer at 4 °C until processing.

The selection of ripe and unripe *Guava* were obtained using the experience of the harvesting people how select the fruit based on their skin color. Such experience was translated to a color match scale in order to select the fruit. Clearly ripe and unripe fruits were used for the experiment (arbitrary scale value of 4 on Fig. 1 and 2).

Figure 1. Ripe *Guava*. From right to left shows skin color levels: 0 to 4.

Figure 2. Unripe *Guava*. From right to left shows skin color levels: 0 to 4.

Before processing, the products were removed from the freezer and cut in 3mm thickness slices. The pH and sugar content (degrees brix) was measured using a pH meter (HANNA, HI 84532-02) and ATC refractometer (MPN: 43217-71864), as shown in Fig. 3 and 4. In general, one expects the ripe fruit to be sweeter and with lesser acidity that the unripe fruit, however, for the samples studied here, no significant differences were observed (90% confidence interval), probably due to the nonuniform distribution on the genetic variety of the trees and uneven cropping conditions, as show Fig. 5.

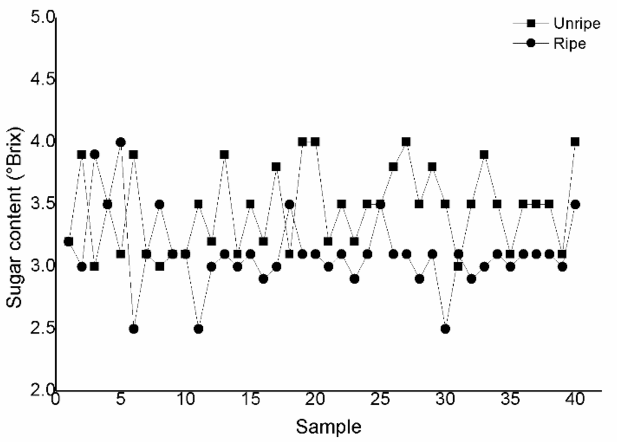

Figure 3. Sugar Content (Degrees Brix): ripe vs unripe, *Guava*.

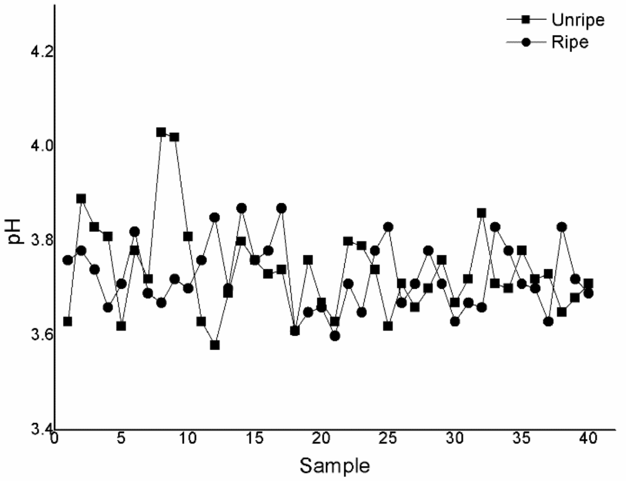

Figure 4. pH: ripe and unripe, *Guava*.

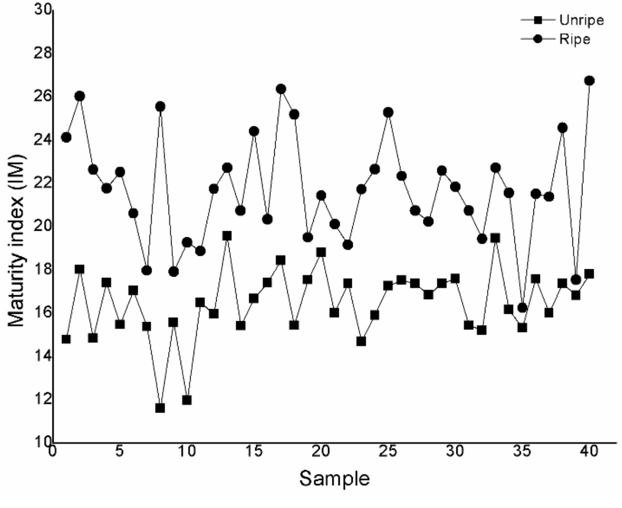

Figure 5.- Maturity index: ripe and unripe *Guava*.

2.1 Experimental set-up

The outdoor drying experiments were performed in Technological institute of Zacatepec from Morelos México, on November 2016, with latitude and longitude of 18.653 and -99.184, respectively

The indirect solar dryer used in this experiment consisted of two parts: drying chamber and solar collector. The products were introduced in the drying chamber. The chamber was built in stainless steel. Chamber size is: 100 x 46 x 125 cm, as shown in Fig. 6 and 7.

Three drying trays were used and were placed vertically with 7 cm betwees each other. The drying chamber can accommodate up to 15 trays. The trays were built form aluminum frame and nylon mesh. Trays size is 88 x 41 cm, as show in Fig. 7 b).

Temperatures was measured into the drying chamber with a DTH22 sensor and stored in the computer through a microcontroller (Arduino Mega). Temperature measurements have a ±0.1°C precision.

Drying air was introduced to the drying chamber for forced convection. Drying air was forced into the chamber by two fans (NMB, 12 V, 0.3 A). Air flow velocity was controlled at 0.7 m/s as measured by an anemometer (AMPROBE TMA-10A, range 0.40 to 25 m/s) at the input of the drying chamber.

The solar collector size is 221.5 x 96 x 13 cm. Solar collector was oriented to the south with a 25° slope, as shown in Fig. 6. It was built of stainless steel with clear acrylic cover, and black mate pipes to absorb the solar radiation during the day. It includes an aluminum sheet below the pipes to reflect solar radiation and polyurethane foam 3 cm thickness for thermal insulation, in order to reduce outward heat loss.

The outdoor drying experiments were performed in Technological institute of Zacatepec from Morelos México, of November month of 2016. With latitude and longitude of 18.653 and -99.184, respectively.

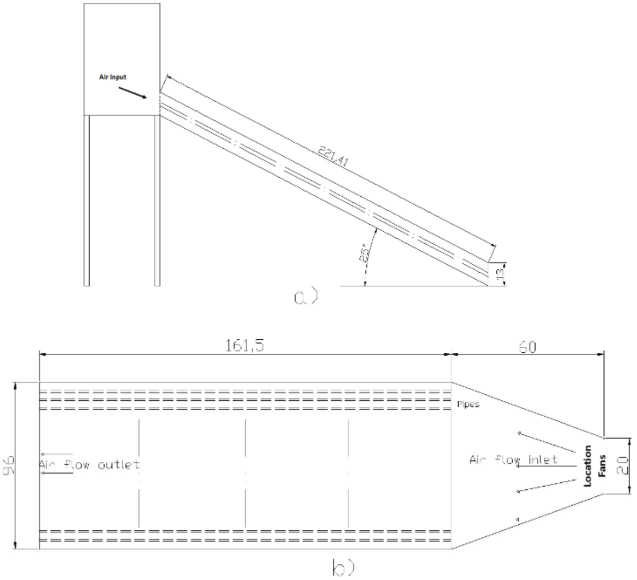

Figure 6. Indirect solar drying. a) solar collector slope. b) rigth to left shows air flow track. All dimensions are in centimeters.

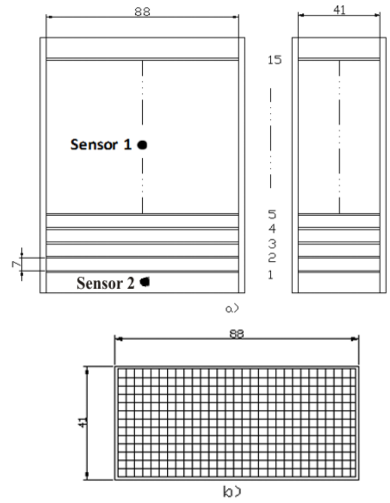

Figure 7. Drying chamber dimensions: a) drying trays to 7 cm spaced (15 capability unit). b) tray size.

2.2 Mathematical modelling of drying curves

Drying curves were experimentally obtained and simulated using Fick´s model. The Fick´s diffusion equations were solved through the following assumptions: moisture was distributed uniformly through the sample mass; mass transfer is symmetric to the center; equilibrium between moisture surface and surrounding air; negligible mass transfer resistance at the surface as compared to internal resistance of the sample; mass transfer takes place by diffusion; diffusion coefficient is constant and shrinkage is negligible [15, 16]. Under these assumptions, the solution of the Fick's diffusion equation is given by Eq. 1: [15, 17-20]:

$$MR = \frac{M-M_e}{M_0-M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}exp^{\left[-(2n-1)^2\frac{\pi^2 Def\ t}{4L^2}\right]} \qquad (1)$$

Here, M stands for moisture content at a specific time, M_o for initial moisture content, M_e for equilibrium moisture content, D_f for effective diffusion coefficient and L for the half thickness of slab. For long drying times, Eq. 1 can be further simplified as shown in Eq. 2 and can be also written in a logarithmic form as shown in Eq. 3:

$$\frac{M-M_e}{M_0-M_e} = \frac{8}{\pi^2}exp^{\left[\frac{\pi^2 Df\ t}{4L^2}\right]} \qquad (2)$$

$$\ln\left(\frac{M-M_e}{M_0-M_e}\right) = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 Df\ t}{4L^2} \qquad (3)$$

Effective diffusion coefficient is predicted by calculating the slope from the drying time versus experimental values of logarithmic moisture ratio (ln (MR)). It can be seen that the plot is a straight line in the graph between drying time (t) and ln (MR) of Eq. 2, and slope of this straight line is calculated by Eq. 4 [21].

$$\frac{\pi^2 Df\ t}{4L^2} \qquad (4)$$

Effective diffusion coefficient usually depends on composition, moisture content, temperature and the type of the material.

3. Results and discussions

Before studying the drying process, moisture content of ripe and unripe Guava was obtained, as follow: 82.11 and 77.95 %. Measured by a Ohaus MB45 moisture balance apparatus at 100°C. The experiments were repeated for four times to obtain an average of the weight loss. The weight loss was of below of 20 %, after of 110 min, as show in Fig. 8.

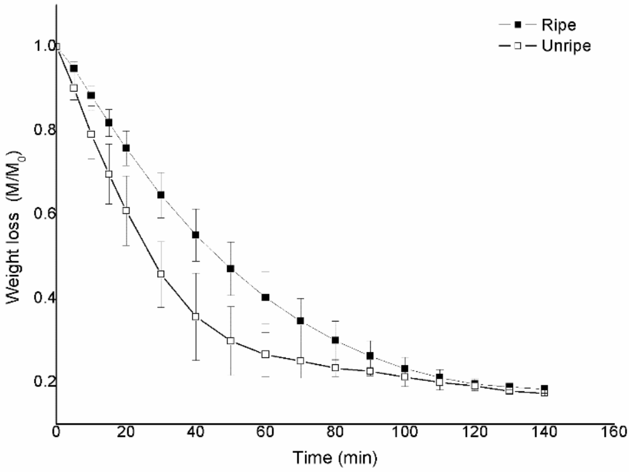

Figure 8. Weight loss between: ripe and unripe *Guava*. *M* and *M₀* are given in *(g/g)*. Drying temperature in the process was *100 °C.*

3.1 Thin layer drying kinetics

Drying kinetics of a material depends on the material moisture and evaporation intensity throughout time related to experimental variables such as sample moisture and equipment size. The weight loss averages for ripe and unripe Guava are shown in Fig. 9 and 10. As can be observed, the drying kinetic of ripe and unripe Guava was strongly influenced by temperatures between the 120 to 360 min that correspond of 11:00 to 15:00 hrs of the day, as show in Fig. 11. Thus, higher temperatures reduce significantly the moisture in the drying process of ripe and unripe Guava. Both Figures show rapid water loss at the beginning of the drying process, in the times described. Water content loss is variable during the experiment due to the variation in temperature induced for the variable solar radiation during the day. This event occurs when higher air temperatures produce higher drying velocity [22], due to the corresponding increase in heat transfer convection coefficient. Also, it can be observed that the drying kinetics of ripe-unripe Guava have similar characteristics as for most tropical fruits. The results show a moisture and weight loss below 20 % is achieved, for both ripe and unripe Guava. This is obtained at 250 min in the process of the drying. Later, a slow removal zone occurs due to the water absence that limit the absorption of the energy transported by the radiation and therefore gives a slower drying.

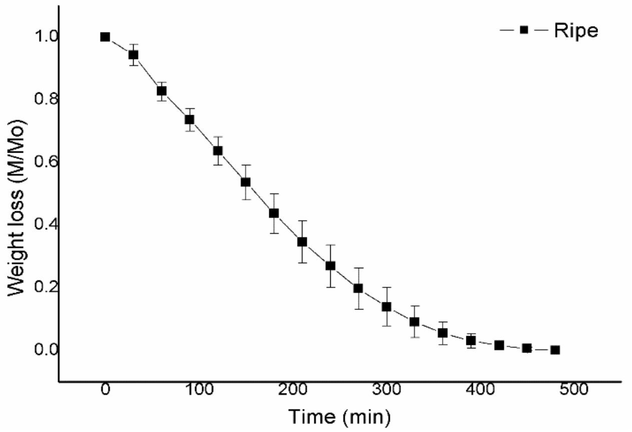

Figure 9. Weight loss average of ripe samples. ***M*** **and** ***M_o*** **are given in** ***(g/g)***

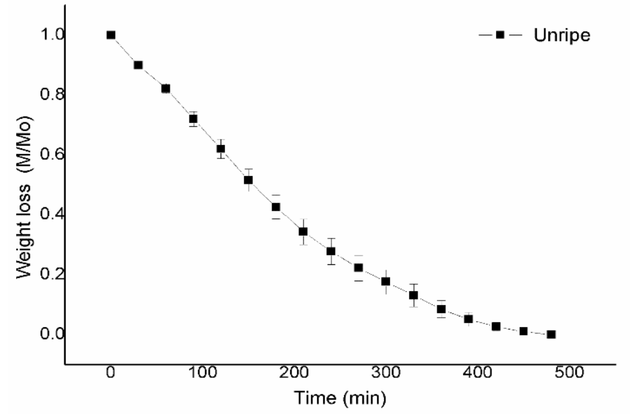

Figure 10. Weight loss average of unripe samples. ***M*** **and** ***M_o*** **are given in** ***(g/g)***

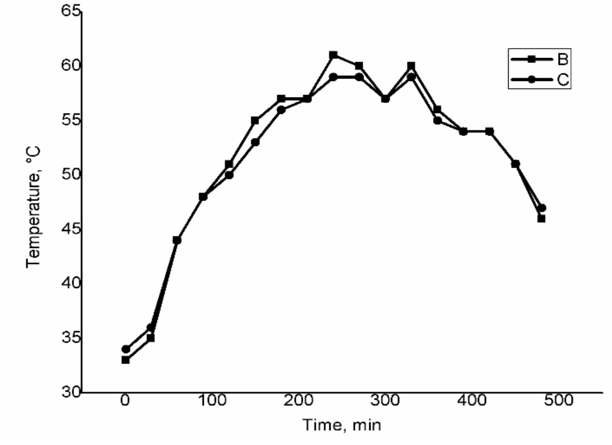

Figure 11. Drying temperatures inside drying chamber, of ripe and unripe *Guava*. The temperature is showed between the 0 to 480 min that correspond of 9:00 to 17:00 hrs, of the day.

The diffusivity coefficient D_f is an effective diffusivity that encompasses effect of several phenomena affecting water loss. Its value is always calculated though mathematical models adjusting experimental data. As diffusivity may vary according to the drying conditions, is not intrinsic to a material. Therefore, through Fick´s models of diffusivity, neglecting sample shrinkage, drying kinetic predictions can be achieved. Also, at higher drying temperatures higher drying velocity is found, because temperature increase favors mass transfer and effective diffusivity increases. Now, when the moisture ratio increases in the products, internal mass transfer resistance decreases. Thus, the average effective diffusivity was found to be: $3.161\text{x}10^{-10}$ m^2/s and $3.038\text{x}10^{-10}$ m^2/s, for ripe and unripe *Guava*, respectively, as show Fig. 12.

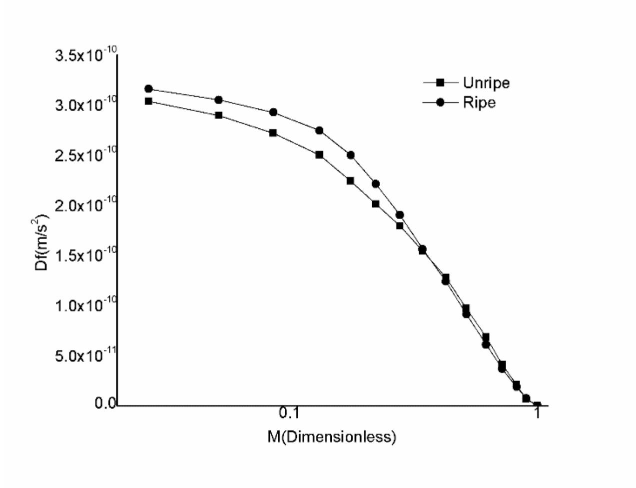

Figure 12 Diffusivity of ripe and unripe *Guava*.

The fruits and vegetables diffusivity coefficients found in other study cases show similarity versus Ripe and Unripe Guava drying by solar indirect drying. With this comparation, solar dryiers can be a great option for the fruits and vegetable drying process that present an approximately equal relative humidity. The drying temperatures obtained inside of drying chamber are above of 50 °C, that correspond between 11:00 a 16:00 hrs of the day and this provides the energy to removal the greatest amount of moisture in the products.

4. Conclusions

Drying kinetics of ripe and unripe *Guava* were studied using a drying solar.

Drying kinetic was strongly influenced for drying temperature: lower temperatures lead to long drying time to obtain products with low moisture value. Fick's models describe properly the experimental data of the drying process.

Effective diffusivity values for ripe and unripe *Guava* were found to be $3.161\text{x}10^{-10}$ m^2/s and $3.038\text{x}10^{-10}$ m^2/s, respectively. Diffusivity value for ripe guava is greater than unripe guava, this because ripeness at the cellular level can be associated with the moisture transport.

Finally, the indirect solar drier can be applied in drying process in diverse fruits and vegetables improving their economical impact in the production zones. The results obtained here can be used to scale the drying process to industrial production levels, considering the maximum temperature, air flows, exchange area and geometric similarity of the drying solar.

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