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Experimentation of the Solar Dryer With Parabolic Trough: Drying of Okra

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Abstract: According to Arthur S. EDDINGTON (1921): "I can prove nothing to you whether you do not let me make any measurements. Measurement is for me the only way to find the laws of nature. I'm not a metaphysicist." In order to confirm the performances of the indirect solar dryer, with Parabolic Trough Collector (PTC). It consists of two essential linked parts: the drying chamber and the reflective concentrator block and the coaxial tubular receiver is housed. The latter is wrapped in transparent pieces of glass, opaque to infrared. This envelope limits the enormous radiative and convective losses. The greenhouse, trapping in addition to direct radiation, will be responsible for the increase in the air temperature, both in the receiver and inside the drying enclosure, thus promotion its natural flow. The performances noted by the numerical results and validated by the value of the Root mean Square Error, RMSE, equal to 4.5°C, between the numerical and experimental temperatures of the heat transfer fluid, at the entrance of the drying chamber, experimental tests of the said dryer were carried out, via the drying of the variety, Clemson spineless, of okra. The diffusion coefficient of dried okra pieces gave satisfactory results, (16.49-22.72) $\times 10^{-10} m^2.s^{-1}$ for cylindrical samples and (6.24-15.59)$\times 10^{-10} m^2.s^{-1}$ for longitudinal slices. These findings are consistent with the literature.

Key words: Solar dryer, parabolic trough concentrator, experimentation, kinetics.

1. Introduction

Solar drying is the most common method of preservation, especially in many African countries.

Unfortunately, this open-air conservation technique produces dried products of mediocre quality. Thus, in-depth studies have made it possible to correct the weaknesses of this technique as well as those of solar equipment, known as indirect solar dryers, with a plan collector [1-3].

These improvements do not always achieve the desired temperature level and drying time [4]. Therefore, the indirect solar dryer, with a solar thermal converter, PTC as an air isolator, seems to be a viable technical-economic compromise, avoiding the cost of improving the thermal performance of a flat plate collector, an alternative to the low energy density of the incident solar radiation [5] and finally, a good response to the problem previously mentioned [4]. To confirm this conclusion, tests related to the drying of okra were conducted. The results are presented here and compared to the literature data.

2. Materials and Operating Procedures

2.1 Materials

In Fig. 1, the different images of the experimental set-up, in use (a) and at the end of drying (b), are shown.

2.2 Operation of the New Solar Dryer

The present solar dryer consists of a parabolic trough, the actual surface of which is covered by an aluminum foil, with an opening width, a = 50 cm, a length of 100 cm, a focal length, f = 10 cm and a depth, h = 15.6 cm.

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(a)

(b)

Fig. 1 Experimental prototype of solar dryer coupled with PTC, (a) in use and (b) at the end of use.

Indeed, an optimal dimension of a solar absorber produces a maximum of useful energy, obtained by the reduction of optical and thermal losses. But, for a large dimension of the said absorber, it results in important thermal losses [6], also obviously a high realization cost.

The receiver is made of a thin steel sheet, rolled up, with a diameter of 10 cm and a length of 140 cm approximately, placed at the focus of the concentrator. The receiver is made up of two coaxial cylindrical tubes, one of which, made of glass, ensures the greenhouse and the second, made of blackened steel, serves as an absorber of the reflected solar flux.

Therefore, the radiative and convective losses are minimized. Also, the losses by convection are reduced by the presence of the vacuum in the annular space between the absorber and the glass.

The whole unit is inclined at 12° to the horizontal, to favour natural convection movements towards the outlet.

The choice of the tubular configuration of the receiver is linked to the fact that the tracking of the sun, in its daily apparent course by the present sensor, is not automatic, thus the solar beam making an angle with the axis of symmetry, does not focus any more correctly!

Built of local materials with sides and bottom insulated with thin polystyrene, the parallelepipedic drying chamber contains trays spaced from each other, arranged in a square face, made of wooden frame and metal grid, on which the products are spread. Access to the trays is possible through a door placed in the back side of the drying chamber.

2.3 Procedure

The okra variety used in our experiments was Clemson Spineless (Fig. 2). This is the variety that we found available at the place of purchase and its optimum production is in the off-season, when it is very successful because of the very high prices of okra at that time. It is an early variety and very productive (25 to 30 t/ha). It was bought very early in the morning (around 06h) in a field. After the purchase, when arriving at the site of the experiments, samples were sorted according to their length and diameter. To prepare them, the stems and the end of the cap had to be cut. Different cuts have been realized, including: the cylindrical cut (heights 1 cm, 1.5 cm and 2 cm) and the longitudinal cut in two sectors (lengths 1cm, 1.5 cm and 2 cm). Finally, these samples were weighed, arranged on racks and placed in the oven. All these steps are shown in Fig. 2.

3. Exploitation of the Results

3.1 Dry Mass and Initial Water Content

To obtain the dry mass, m_s, of the various dried samples were placed in an oven, brand Memmert at 70°C for 24 hours [7]. After this stay in the oven, the dry mass of said sample is noted, m_s. Therefore, the initial water content in dry basis X_0 is determined

Fig. 2 Stages of drying.

according to the following equation (1):

$$X_0 = \frac{m_0 - m_s}{m_s} \tag{1}$$

3.2 Water Content and Absolute Humidity of Okra

The water content in dry basis a time t is determined by the mathematical $X(t)$ during drying at expressions (2) and (3):

$$X(t) = \frac{m(t) - m_s}{m_s} \tag{2}$$

Or again

$$X(t) = \frac{m(t)(X_0 + 1) - m_0}{m_0} \tag{3}$$

Where $m(t)$ is the mass of the okra at each time t of drying and m_s its dry or anhydrous mass.

The wet basis or absolute moisture content of the product is X_h determined according to the expression of P. Monneveux (1991) [8]:

$$X_h = \frac{m(t) - m_s}{m_0} \times 100 \tag{4}$$

With m_0, the initial mass (or fresh mass) of the okra. The relations that allow us to go from one definition to the other are equations (5) and (6):

$$X = \frac{X_h}{1 - X_h} \tag{5}$$

$$X_h = \frac{X}{1 + X} \tag{6}$$

3.3 Drying Speed

It allows to evaluate the quantity of water lost in the different dried okra samples per unit of time. It is determined according to the following relationships (7), (8) and (9):

At $t = t_0$, $$V_0 = \frac{X_1 - X_0}{t_1 - t_0} \tag{7}$$

At $t = t_i$ $(i=1,2... n-1)$

$$V_i = \frac{X_{i+1} - X_{i-1}}{t_{i+1} - t_{i-1}} \tag{8}$$

At $t = t_n$ $$V_n = \frac{X_n - X_{n-1}}{t_n - t_{n-1}} \tag{9}$$

3.4 Diffusion Coefficient

The diffusion coefficient gives us an idea of the speed of movement of water and the amount of water passing through a given surface.

It is obtained by applying the analytical solution of Fick's second law for biological products, depending on the cutting geometry of the product [9].

- Cylindrical cut

$$\frac{\partial X}{\partial t} = \frac{1}{r}\left(\frac{\partial}{\partial r}\left(D\, r \frac{\partial X}{\partial r}\right)\right) \tag{10}$$

- Longitudinal cut

$$\frac{\partial X}{\partial t} = D \frac{\partial^2 X}{\partial x^2} \tag{11}$$

The analytical solution of these equations is given by equalities (12) and (13), taking into account the cutting shapes.

- Cylindrical cut

$$MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} = \frac{4}{\beta^2}\exp\left(-\frac{\beta^2 D t}{r_c^2}\right) \quad (12)$$

- Longitudinal cut

$$MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D t}{4L^2}\right) \quad (13)$$

X_0 (in g/g$_{waterms}$) are respectively the average, equilibrium and initial water content of the product;

D (in $m^2.s^{-1}$) is the diffusion coefficient; r_c (*in m*) is the radius of the cylindrical cut; L (*in m*) is the characteristic length of the longitudinal slice; and t (*in s*) is the drying time.

4. Results and Discussion

4.1 Dry Mass and Initial Moisture Content of Okra

A quantity of 107.52 g ± 0.01g of fresh okra (m_0) is placed in the oven, set at 70°C for 24 hours. At the end of this stay, the dry mass of the said sample (m_s) was recorded and is worth: 12.82g ± 0.01 g. Thus, the value of the initial was recorded and water content is obtained, using Equation (1).

It is worth: X_0 =7.38g$_{eau}$/g$_{ms}$, or in wet basis, X'_0 = 88.07%.

This value is consistent with the literature. Indeed, the range of initial moisture content of okra is 88-90% and the final moisture content is 5-10%, in wet basis [10].

4.2 Influence of Cut Shapes

Two different shapes of section (round and longitudinal), of varying height and length (1 cm and 2 cm), were made. The initial mass of the product to be dried was 207.7 g for each of the 4 cuts. The drying process started at 8:30 am and stopped at 5:30 pm on the first day, then continued the next day from 8:05 am to 5:05 pm, a period during which the solar radiation was good. At the end of this experiment, the mass results of the samples are presented in Table 1.

According to this data, the longitudinal section have evacuated more water than the cylindrical slices and therefore dry faster than the latter.

Also, the amount of water evacuated depends not only on the shape of the cut, but also and especially on the size (length and/or height) of each piece. This will be verified later (Table 2) with regard to the values of the said samples.

Differences in final weight due to cut shape and size (length and/or height) were observed on dried samples. The reduction in moisture content of okra during the first day was higher than that found on the second day, based on the values shown in Table 2. A similar fact was found by Wankhade et al. (2013) [11].

Table 1 Balance sheet for the 1st day of drying okra.

Cutting shapes	Initial mass (in g)	Final mass	Evacuated water mass
Length, 1 cm	207.7 ± 0.1	37.3 g	170.4 g
Length, 2 cm	207.7 ± 0.1	49.7 g	158.0 g
Round, 1 cm	207.7 ± 0.1	80.2 g	127.5 g
Round, 2 cm	207.7 ± 0.1	100.1 g	107.6 g

Table 2: Results of Okra Drying on 2nd Day

Form of cuts	Initial mass	Final mass(in g)	Evacuated water mass
Length, 1 cm	36.3 g	22.3 ± 0.1	14.0 g
Length, 2 cm	48.2 g	22.4 ± 0.1	25.8 g
Round, 1 cm	78.8 g	22.5 ± 0.1	56.3 g
Round, 2 cm	98.1 g	23.2 ± 0.1	74.9 g

The amounts of water lost decreased much more on the second day than on the first day. An opposite finding to the first day is noticeable on the second day of drying, regarding the amount of water lost in the same samples. The slices that lost more water on the first day lost less this time. This is certainly due to physical deformations (shrinkage) of the structure of samples and to the level of the pores, blocked by soluble nutrients (salt and sugar). A fictitious “drying front” line was formed, moving from the hot air attack front to the product exit surface, beyond which the air with be unable to dry further [12].

4.3 Influence of the Cutting shape on the Drying Speed

Fig. 3 shows the influence of the cut shape on the drying speed. These are the longitudinal (1 cm and 1.5 cm) and cylindrical (1 cm and 1.5 cm) cuts. The drying speeds are monitored as a function of drying time. It can be noted that on these graphs (a and b) that the drying speed of the longitudinal cut is higher at the beginning of the drying than that of the cylindrical piece. After about 4 hours of drying, the situation is reversed until the end. This could be related to the exchange surface between the air and the product, which is larger for the longitudinal slice.

4.4 Influence of Product Location on Drying Speed

The location of a product to be dried in the drying chamber influences the drying process, in particular the drying speed, as can be seen in Fig. 3.

The three curves obtained by smoothing all have two phases and two periods:

- During the first period, from 0 to 450 minutes of exposure, the loaded racks give a decreasing speed. Also, the speed of the sample on rack 1 is higher than that of the next rack, which in turn is higher than the speed of the last rack.
- During the second period (more than 450 minutes), the drying speed of each of the racks is reversed, due to the collapse of the samples, thus blocking the water migration phenomenon of the product.

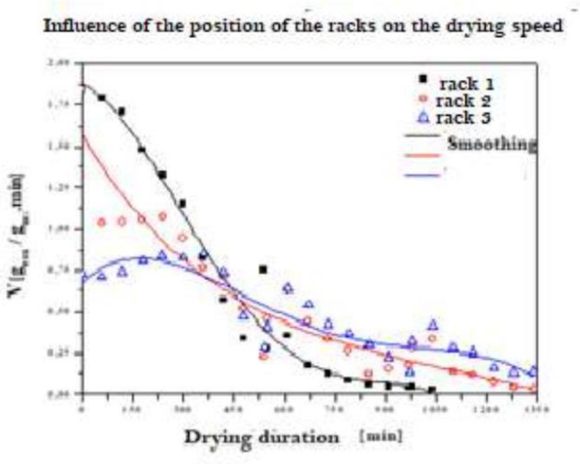

Fig. 3 Influence of the position of the racks on the drying.

4.5 Diffusion Coefficient Values

The experimental data allow us to determine the diffusion coefficient of two cuts of okra, longitudinal and cylindrical, recorded in Table 3.

Table 3 Diffusion coefficient values of okra shices.

Cutouts	Dimensions (cm)	D ($\times 10^{-10} m^2.s^{-1}$)
Longitudinal	Length = 1	6.24
	Length = 2	15.59
Cylindrical	h = 1	22.72
	h = 1.5	20.48
	h = 2	16.49

The values of the diffusion coefficient obtained make it possible to appreciate the present drying technique. The higher the diffusion coefficient, the faster the transfers. In the present work, the diffusion coefficient of the cylindrical cutout shows this.

Diffusion was faster in the lower height samples than in the higher ones. This shows that the diffusion takes place in the direction of flow of the drying air.

In the longitudinal slice samples, the phenomenon is reversed. Indeed, the quantity of water contained in the longitudinal slice of 1 cm is less important than that of 1.5 cm length.

The diffusion is higher in the cylindrical cut than in the longitudinal cut. This may be related to the fact that following the longitudinal cut arrangement in the dryer, on the skin, constituting braking to heat transfer in these samples during drying [13].

Otherwise, the longitudinal samples have less water to evacuate than the cylindrical ones; this partly justifies the values of D (diffusion coefficient).

Compared to the literature, we have the data grouped in Table 4.

Table 4 Diffusion Coefficient of Okra in the Present Work and in the Literature

Authors	D ($\times 10^{-10} m^2.s^{-1}$)	Cutouts	Dimensions
G. Ouedraogo	6.16	Longitudinal	
Present work	16.49-22.72	Cylindrical	R = 0.7 cm
Dadali et al.	20.52-86.17		
I. Doymaz	4.27-13.0	Whole okra	

The differences could be justified either by the drying conditions; some of them are done with the help of microwave, or by the effect of temperature which influences the drying [13-14], or related to the thickness of the sample [15-17], to the varieties of okra, to the type of drying equipment used, globally to the operating conditions and other uncontrolled parameters.

5. Conclusion

A parabolic trough collector, solar-thermal converter was manufactured and attached to a drying cage, thus forming an indirect solar dryer. In this article, it has been conducted an experimental campaign of the said dryer, via the drying of okra, of the Climson spineless variety. The diffusion coefficient values of the different dried okra samples indicate the performance of the present dryer. These coefficients take into account the shape and size of the dried okra slices.

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