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Experimentation of a Forced Convection Solar Dryer for Drying Sweet Potatoes at the Higher Institute of Technology of Mamou-Guinea

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Abstract

This study was carried out at the Mamou Higher Institute of Technology during the period from March 10 to April 15, 2022, with the aim of designing and testing a solar dryer with forced convection by drying potatoes. The dryer was designed using local materials. Its main geometric parameters are: 1) height of the drying chamber (90 cm), 2) length of the drying chamber (50 cm), 3) width of the drying chamber (43 cm), 4) surface of the racks (0.1806 m^2), 5) surface of the heat accumulator (0.2537 m^2). The experiment focused on the vacuum test of the dryer for two days and that of the drying of the sweet potato for three days from 8:30 a.m. to 5:30 p.m. The average vacuum test temperature values of the three environments are respectively accumulator (43˚C), dryer chamber (41˚C) and ambient environment (34˚C). Four kilograms (4 kg) of boiled sweet potato were dried. The average temperatures in the accumulator and in the drying chamber during the three days of drying are respectively 33˚C and 39˚C. The final mass of the dried product is 1.2 kg, with a quantity of water extracted of 2 liters or 63% of the initial mass of the product. The average drying rate is 0.074 kg/h. The drying kinetics showed a decreasing rate in the absence of the heating period and the constant rate period.

Keywords

Experimentation, Temperature, Accumulator, Forced Convection, Solar Dryer, Sweet Potato

1. Introduction

The incessant increase in the price of fuel and gas of petroleum origin, the fight against deforestation and the concern for the protection of the environment push us today to seek new energies. These new energies must be renewable and non-polluting. Thus, among these energies, we have solar energy which is the subject of many research subjects because of its availability in large quantities all over the world [1]. Solar drying is a cost-effective means for the valorization of agri-food products. It makes it possible to safeguard the nutritional elements of the product. In the agri-food sector, it makes it possible to convert perishable foodstuffs into stabilized products, by lowering water activity [2].

The solar dryer is a device that captures the sun's rays to dry or dehydrate the food (fruits, vegetables, herbs, fish, meat, etc.) placed inside. Drying is the operation whose purpose is to partially or totally eliminate water from a wet body by evaporation of this water [3]. Drying food in the sun and in the open air is an ancestral practice that does not always produce good quality products. Improved techniques for using solar energy are little known, but nevertheless make it possible to obtain economical, ecological products of better quality (color, flavor, taste, texture, aroma) and are easy to use [4] [5].

Nevertheless, it should be noted that the efficiency of outdoor drying processes is low given the many hazards (weather, insects, rodents, etc.). To improve these traditional techniques, drying devices operating from various energies have been developed. Among these devices, solar dryers prove to be a particularly interesting solution [6]. This technique has been the subject of many scientific papers and still remains today a privileged field of research, particularly in countries where the use of traditional methods is still essential [7] [8] [9].

In Guinea, fruit drying has been known for a very long time. Due to the coincidence of fruit production periods with the rainy season and for economic reasons, it has become a safe way to reduce losses due to the lack of outlets for fresh fruit and the lack of unity of industrial processing [10].

This study focuses on the drying of sweet potato (*Ipomoea batatas.* Lam) from a forced convection solar dryer.

Sweet potato (*Ipomoea batatas.* Lam) is a perennial herbaceous plant whose cultivation is widespread in all tropical and subtropical regions where it is grown mainly for its edible tubers, rich in starch. It is very rich in provitamin (A) and also provides long-lasting energy thanks to the starch it contains. The nutritional value of the potato is linked to its composition, mainly to its dry matter content, which consists mainly of carbohydrates, but which also provides proteins, vitamins, mineral salts, dietary fibers and only traces of lipids [11].

In Africa, the total production is 8.5 million tons, which corresponds to less than 10% of the world harvest. Developing countries produce 98.5% of the world's production, which justifies its status as the "culture of the poor". Yields vary widely depending on the geographical area and oscillate between more than 21 t/ha in China and only 4 t/ha in Africa [12]. The initial water content of the potato is approximately 78% of the mass of the product. It is considered dry if its water content represents 10% of its final mass. The temperature of the drying fluid varies between 35˚C to 55˚C and the load density of the racks for convective solar drying must be less than 2 kg/m^2.

Tuber formation can be clustered around the stem, sparsely or very sparsely. Several types of tuber shape can be observed: round, round elliptical, oval, oblong, long oblong, long elliptical, curved. The chemical composition of sweet potato depends on the variety, the type of soil and the period of cultivation. It is a nutritious vegetable and an excellent source of vitamins; its chemical composition and nutritional value are among others: Proteins (1.69 g), Lipids (0.15 g), Saturated fatty acids (0.043 g), Carbohydrates (12.2 g), Sugar (6.11 g), Fiber (2.9 g), Provitamin A (10500 µg), Vitamin A (1750 µg), Vitamin B9 (6 µg), Vitamin C (16.2 µg), Vitamin E (0.83 µg), Iodine (3 µg), Calcium Iodine (32.5 mg), Copper (0.13 mg), Iron (0.71 mg), Magnesium (22.5 mg), Phosphorus (43 mg), Potassium (353 mg), Sodium (31.5 mg), Manganese (0.38 mg) and Zinc (0.26 mg) [13].

The general objective of this work is to design and build a solar dryer to produce hot air to indirectly dry food products. The specific objectives of this study are as follows: the sizing, design and experimentation of the device by the vacuum test and by the drying of 4 kg of sweet potato at the Higher Institute of Technology of Mamou in Guinea.

2. Material and Method

2.1. Material

2.1.1. Description of the Study Area

Located 275 km from Conakry (Capital of the Republic of Guinea), the Prefecture of Mamou, capital of the administrative region of Mamou is between 9˚54' and 11˚10' North latitude and 11˚25' and 12˚26' West longitude with an average altitude of 700 m. It is the hinge between Lower Guinea, Middle Guinea and Upper Guinea, covering an area of 8000 km^2 with a population of 236,326 inhabitants, *i.e.* an average density of 28 inhabitants per km^2. Its climate is of the Foutanian type, characterized by the alternation of two seasons of equal duration, a dry season from November to April and a rainy season from May to October [14].

2.1.2. Equipment for the Design, Construction and Testing of the Dryer

The design and construction materials of the dryer are: plywood, wooden planks, galvanized sheet metal, wooden cleats, wooden strips, silicone insulation gasket, glass and plastic plate, black paint box (Spray paint), screws, spikes, hinges, door lock and mesh. The electrical equipment consists of a photovoltaic panel with peak power (15 Wp), maximum voltage (9 V), maximum current (0.61 A); three (3) fans, each with a nominal power of (4.8 W), a voltage of (12 V) and a maximum current of (0.4A) and a capacity battery (10 Ah). The equipment and tools for experimenting with the dryer are: sweet potato, dial scale, multimeter and temperature sensor.

2.2. Method

The different stages of this study are: dimensioning, design and experimentation of the dryer. Each step of this work is carried out according to a well-structured methodology.

2.2.1. Design

The solar dryer generally consists of two main parts, namely: the drying chamber and the solar collector or heat accumulator. Its operation is based on the phenomena of heat exchange (radiation, convection and conduction) [15]. The sizing of the dryer consisted in determining the following geometric parameters: the length, the width, the height, the drying chamber, the drying chamber, the surface of the rack, the useful volume of the dryer, the solar collector or heat accumulator.

2.2.2. Experimentation

The experiment focused on the vacuum test of the dryer (performance of the dryer) and that of the drying of the sweet potato in the enclosure of the courtyard of the Higher Institute of Technology of Mamou. It consisted of taking temperature measurements on the various racks in the drying chamber and in the environment for two days using temperature sensors and a multimeter. Then 4 kg of sweet potato were dried. The potato was boiled with three liters of water for 40 minutes. After cooking, we peeled and cut into small pieces of 0.25 to 0.30 cm, then weighed again, we obtained 3.2 kg, it is this quantity which was distributed equitably on the four racks, *i.e.* 0.8 kg per rack. Temperature readings in the drying chamber and in the ambient medium were taken every 30 minutes. The parameters of the drying process are: the mass of water to be extracted from the product, the volume of air required for drying, the minimum energy required for drying, the minimum drying power, the drying speed and the drying kinetics.

1) *Mass of water to be extracted from the product*

The mass of water (Δm) to be extracted from the product is the difference between the initial mass (m_i) of the fresh product and the final mass (m_f) of the product after drying, (formula (1)) [16].

$$\Delta m = m_i - m_f \tag{1}$$

The mass of each sample, measured regularly until thermodynamic equilibrium, makes it possible to determine the equilibrium water content using relation (2) [17].

$$C_{\text{water}} = \frac{m_i - m_f}{m_f} \tag{2}$$

2) *Volume of air required for drying*

The volume of air (V_a) required for drying is determined by formula (3).

$$V_a = \frac{m_{as}}{\rho_a} \tag{3}$$

where: V_a: volume of air required for drying; m_{as}: mass of air required for drying; ρ_a: air density.

3) *Energy required for drying*

The minimum energy ($E_{\min}$) required for drying is determined by formula (4).

$$E_{\min} = \Delta m \times L_w \tag{4}$$

where: Δm: mass of water extracted from the product (kg), L_w: Enthalpy of water (kJ/kg).

4) *Drying power*

For a given time (t), the minimum power ($P_{\min}$) supplied to the air for drying is determined by formula (5).

$$P_{\min} = \frac{E_{\min}}{t} \tag{5}$$

The minimum power ($P_{\min}$) is the threshold power which causes the evaporation of the water contained in the product. In order to ensure this evaporation, the drying power (P_s) must be greater than or equal to the minimum power (Pmin), "$P_s \geq P_{\min} v$". Thus, the minimum power ($P_{\min}$) is modulated by 10% to obtain the drying power [18]. The drying power is therefore determined by formula (6).

$$P_s = (1 + 10\%) P_{\min} = 1.1 \times P_{\min} \tag{6}$$

5) *Drying speed*

The drying rate (V_s) is the ratio between the mass of water (Δm) evaporated from the dried product per unit time, (formula (7)). The drying speed depends on certain parameters such as: the nature, the porosity, the shape and the humidity of the product, the temperature, the humidity and the speed of the air. The limit of the quotient of the difference in content (Δm) by the time interval (Δt) characterizes the pace of the transfer [19].

$$V_s = \frac{\Delta m}{\Delta t} \tag{7}$$

The different experimental steps of the drying process are illustrated by the photos in **Figure 1**.

3. Results and Discussions

3.1. Results

The results obtained relate to the sizing values of the geometric design parameters and the experimentation of the dryer.

3.1.1. Geometric Parameters of the Dryer

The design results and the dimensions of the geometric parameters of the designed dryer are shown in **Table 1**.

Photo 1: Weighing the fresh sweet potato

Photo 2: Cooking the sweet potato

Photo 3 : Weighing the boiled potato, peeled and cut

Photo 4: Exposure of the potato on the different racks

Photo 5: Taking temperature

Photo 6: Dried potato

Figure 1. Experimental steps of the drying process.

3.1.2. Experimentation of the Dryer

The results of the dryer experiment relate to the vacuum test and the drying of sweet potato (Table 2).

3.2. Discussions

The results obtained during this study are represented by the diagrams of the figures below for their interpretations and discussions.

Experimentation of the Dryer

1) *Vacuum test of the solar dryer*

Figure 2 shows the temperature variation curves in the environment, the drying chamber and in the heat accumulator. Figure 3 illustrates the variation in average temperatures in the three environments (ambient, drying chamber and accumulator) during the two test days.

Table 1. Values of the geometric parameters of the dryer.

NO	Designation	Symbol	value	Unit
1	Height of the drying chamber	H	90	cm
2	Length of drying chamber	Ldc	50	cm
3	Width of drying chamber	Wdc	43	cm
4	Length drying rack	Lh	43	cm
5	Width drying rack	Wh	42	cm
6	Surface drying rack	St	0.1806	m^2
7	Useful volume of the dryer	Vu	0.086	m^3
8	Total volume of the dryer	Vt	0.220	m^3
9	Length of heat storage	Lhs	50	cm
10	Width of lake heat storage	Whs	40	cm
11	Heat store height	Hsh	20	cm
12	Heat storage area	Ssh	0.2	m^2
13	Heat storage volume	Vhs	0.04	m^3

Table 2. Mass of water extracted, energy, power and average speed of the drying process.

NO	Designation	Symbol	Value	Unit
1	Mass of water extracted from the product	Δm	2	kg
2	Minimum energy	$E_{\min}$	293.28	kJ
3	Minimum power	$P_{\min}$	4.073	W
4	Drying power	P_s	4.480	W
5	Average drying rate	V	0.074074	kg/h

Figure 2 shows the temperature variation curves of the three media (ambient, drying chamber and accumulator) have the same appearance. However, the temperatures in the heat accumulator and in the drying chamber remain higher than that of the surrounding environment. The curves of the first test day (03/25/2022) are all relatively above the curves of the second (03/26/2022); this is due to strong sunshine on the first day.

The average temperature curves in the accumulator and in the dryer chamber are above that of the ambient environment (**Figure 3**), the average temperature values during the empty test period are respectively accumulator (43˚C), drying chamber (41˚C) and ambient environment (34˚C), with respective differences, between drying chamber and ambient environment (7˚C), between accumulator and ambient environment (9˚C) and accumulator and drying (2˚C). This shows a good performance of the dryer. These values are relatively equal to those of other authors [20] [21].

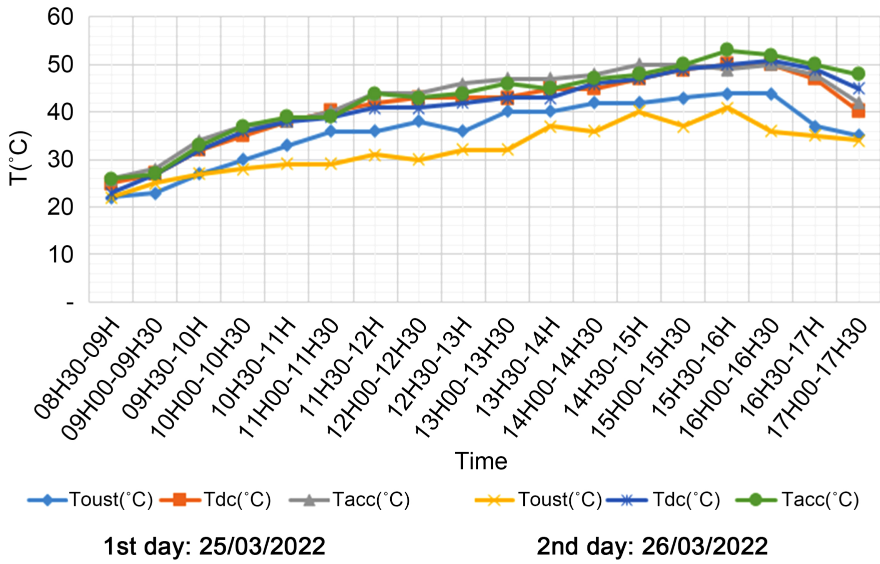

Figure 2. Variation of no-load test temperature.

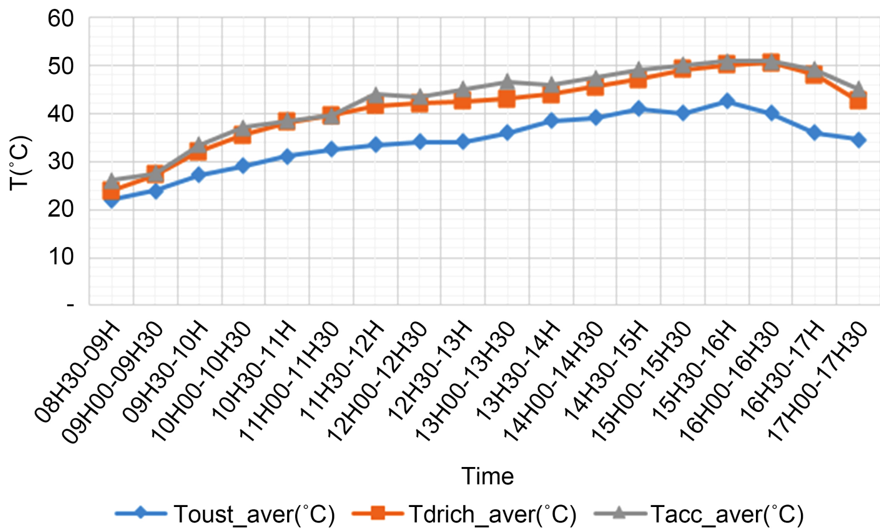

Figure 3. Average no-load test temperatures.

2) *Sweet potato drying temperatures*

The variation curves of daily and average sweet potato drying temperatures are illustrated in Figure 4 and Figure 5.

During the three days of potato drying, the temperature variation curves in the accumulator, in the drying chamber and in the ambient environment have almost the same appearance (Figure 4 and Figure 5). The temperature curves of the accumulator, of the drying chamber always remain above that of the ambient environment. The average temperatures in the accumulator and in the drying chamber during the three days of drying are respectively 33˚C and 39˚C (Figure 5). These average temperatures are relatively low compared to those of the vacuum test of the dryer. This is due to the presence of wet potato in the drying chamber of the dryer [22].

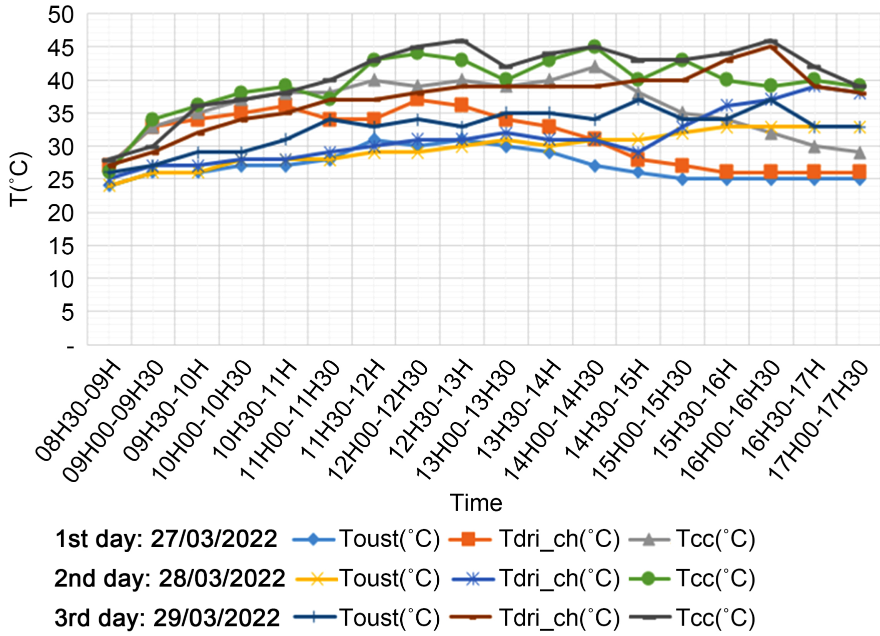

Figure 4. Sweet potato drying temperatures.

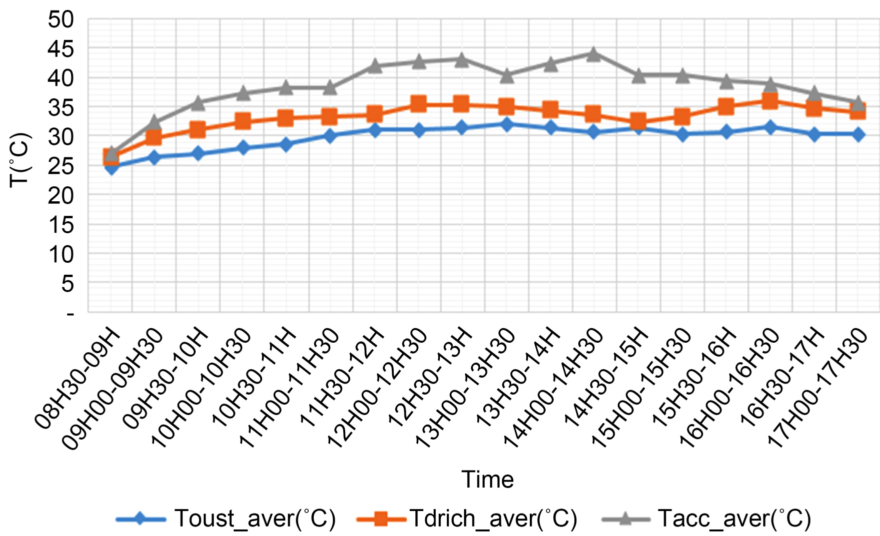

Figure 5. Average sweet potato drying temperatures.

The maximum average temperatures were observed on the third day (31/03/2022) *i.e.* 41˚C in the accumulator, 37˚C in the drying chamber and 33˚C in the ambient environment; this is explained by two phenomena; the product was already almost dried and good sunshine [23].

3) *Rack drying kinetics*

The rack drying kinetics is shown in **Figure 6**.

Figure 5 shows that the drying kinetics on the different racks conform to the drying phase principle (the heating phase, the phase at constant speed and the phase at decreasing speed). Before exposure of the dryer to the sun on 03/27/2022 all the racks had the same quantities of product (0.8 kg of potato), after the first day of drying on 03/28/2022 the mass of the product decreased at the level of each rack, either rack I (0.50 kg); hurdle II (0.51 kg); hurdle III (0.55 kg) and hurdle IV (0.60 kg). Similarly, after the second day of drying there was a reduction in masses, *i.e.*: rack I (0.40 kg); hurdle II (0.42 kg); hurdle III (0.48 kg) and hurdle IV (0.50 kg). After the third day on 03/30/2022 all masses became equal (0.30 kg). Also, after the fourth day the mass of the product on the different ones has no longer varied, which proves that the potato is dried.

The drying process was carried out according to the order of the racks (I, II, III, IV) of the heat accumulator upwards; this is explained by the fact that the humidity extracted at the level of the racks of the bottom is sent to those of the top [24].

4) *Mean potato drying kinetics*

The average potato drying kinetics is shown in **Figure 7**.

The graph in **Figure 7** shows that the potato was dried for three days. The initial mass of the product being 3.2 kg, during the first day of drying (28/03/2022) the mass of the product became 2.16 kg, after the day of 29/03/2022 the mass of the product decreased 1.65 kg. During the last two days from 30 to 31/03/2022,

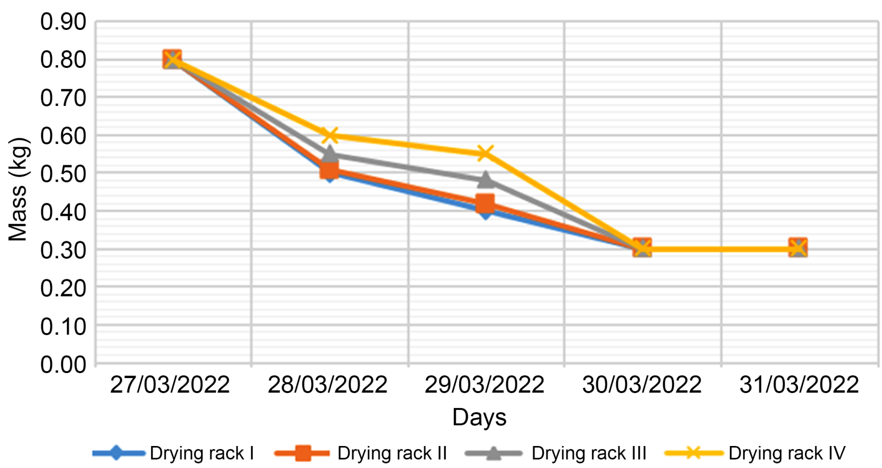

Figure 6. Rack drying kinetics.

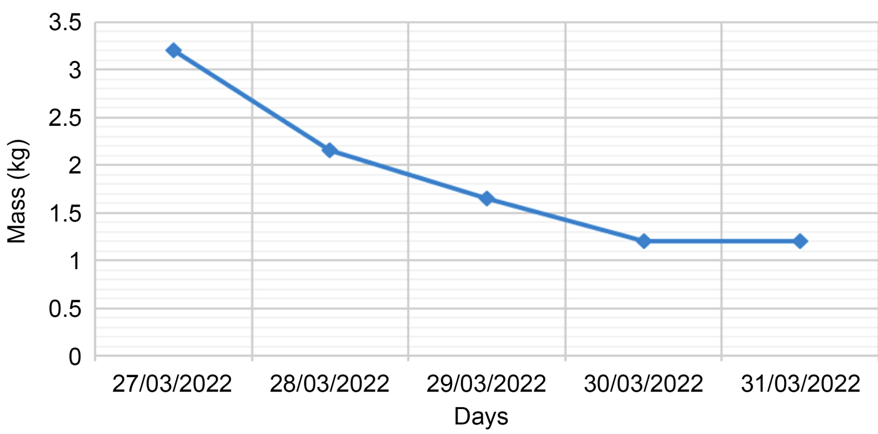

Figure 7. Mean potato drying kinetics.

the value of the mass of the product has not changed either (1.2 kg), which proves that the product is dried with an amount of water extracted from 2 liters or 63% of the initial mass of the product. The drying kinetics has a decreasing rate [25] [26].

4. Conclusions

The conservation of agri-food products after harvest remains a major problem in some West African countries, such as Guinea with nearly eight rains. Thus, this study aimed to improve the technology of drying products for good conservation.

The main results obtained concern: the determination of the geometric parameters of the dryer; the vacuum dryer trial for two days and the sweet potato drying trial for three days. The evolution of potato drying temperature and humidity was monitored. The final mass of the dried product is 1.2 kg, with water evaporation of 2 liters or 63% of the initial mass of the product. The average drying rate is 0.074 kg/h.

The drying kinetics showed a decreasing rate in the absence of the heating period and the constant rate period. The drying speed was not the same on the different racks. Overall, the dried product remains of good quality.

In view of the results obtained, the solar dryer technology for agri-food products must be improved and encouraged in humid areas with low energy rates.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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