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Research Article

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Experimental Study of the Drying Kinetics of Products with High Water Contentapplication on Green Chilli

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Abstract
The main objective of this work is to determine the graphs of relative humidity loss, and the speed of drying for green pepper, to identify the characteristic parameters influencing the drying of products with high humidity content, and to establish satisfactory models that characterize the drying kinetics.

This experimental study was carried out using an indirect type of a solar dryer, which functions in the mode of natural convection, intended for the thermal treatment to medium duration of the agro-alimentary products.

In this work, we are interested in the evolution of the temperature and the mass of the material to be dried, whose manipulations took place in May and July of the year 2009.

Keywords: Solar drying, natural convection, drying kinetics, green pepper, relative humidity.

Introduction

Solar drying is the operation of conservation and recovery that promotes the storage of food, which uses solar energy as a source of heating; it is a very economical method for the dehydration of agro-alimentary products at low temperatures. In the food industry in general, the optimization of the drying operation must meet two essential objectives, which are the limited consumption of energy and the preservation of the aromatic quality of the product to be dried.

The solar dryer used is constructed of locally available tools and materials, which work on the principle of natural convection. This type of dryer is less expensive, simple to build, and suitable for drying agro-alimentary products. The choice of the pepper is justified by its use in the dry state.

In this work, we will present the results of an experimental study of solar drying of an agro-alimentary product (pepper). In this work, we will focus on the experimental approach that consists in determining the kinetic behavior of the agro-alimentary product (pepper) during the drying process under conditions of temperature, speed, and humidity.

Characteristic Equations

The absolute humidity of a solid also called water content is expressed by the mass of liquid contained in the product compared to its dry mass [1].

$$X = \frac{M_h - M_s}{M_s}$$

On the other hand, the relative humidity of a solid, also called water content is expressed by the mass of liquid contained in the product compared to its wet mass [1].

$$X_r = \frac{M_h - M_s}{M_h}$$

Therefore, the drying speed is deduced from the humidity losses characterized by the following formula [1].

$$V = \frac{\Delta X}{\Delta t}$$

The absolute or specific humidity, or moisture content of a gas, is the mass of moisture mixed with a kilogram of dry gas, this humidity designated by Ha, is expressed by the following equation [2].

$$H_a = \frac{M_a}{M_e}$$

Which can be written depending on the total pressure and the partial pressure of steam

$$H_a = 0.622.\left[\frac{P}{P - P_v}\right]$$

The relative humidity is the ratio between the partial pressure of water vapor Pv and the saturated vapor pressure Ps for a given temperature and air volume [1].

$$H_r = \frac{P_v}{P_s}$$

Experimental Device

This is an indirect type of solar dryer, (Fig.3), consisting of an air collector (Fig.1) and a drying chamber (Fig.2).

Figure 1: Flat-plate solar collector

Figure 2: Drying chamber

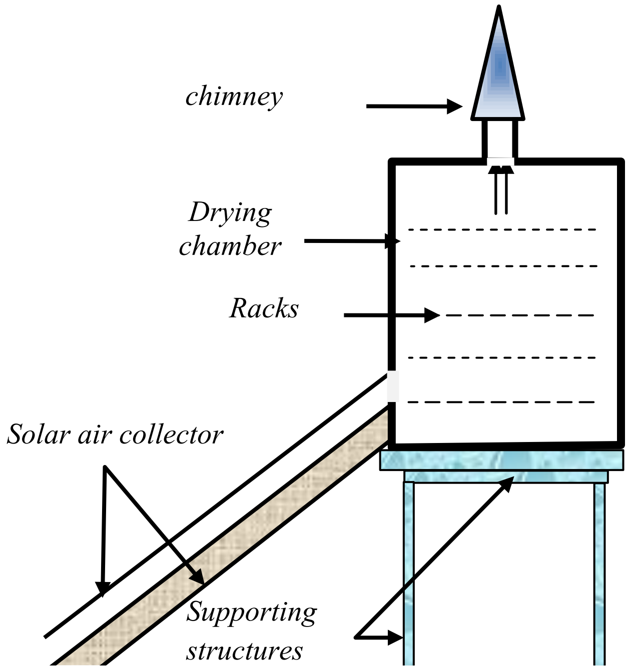

Figure 3: Descriptive Scheme of the Solar Dryer

drying chamber which supports the racks is made of galvanized metal sheet with a thickness of 5 mm, whose useful volume of drying is 0.560 m^3, perfectly calorific in glass wool to ensure good thermal isolation, has 05 racks, the drying surface of each is 0.49 m^2, which corresponds to a total surface of drying of 2.45 m^2.

Before drying the pepper, preliminary preparations should be realized which are:

- Washing off the product to eliminate impurities, mud, insecticide residues, and other contamination.
- Cutting the product into slices.
- The initial mass of the product to be dried is 31 g per rack.
- To monitor the mass loss of the product during the drying process, we measured the weight every hour using a 0.1 g precision scale.
- Measurements of temperature, solar radiation, and airspeed are taken every hour.
- The experimental protocol consists in performing daily drying of the product between 09.00 and17.00 . At the end of each day, the product is stored in a dry place to prevent any rehydration.
- After preparing a sample, we place in the moisture analyzer, which is equipped with a digital scale with an accuracy of 0.001g that measures the mass of the product during operation.
- To follow the evolution of the temperature inside the product, we used a special multifunction device type KIMO equipped with a thermocouple, which can be introduced in the product.
- The humidity and air speed at the inlet and outlet of the sensor or the drying chamber are measured with a multifunctional KIMO device.

Results and Discussion

During the drying process, there is a double transfer of heat and mass. This means that the air at the outlet has higher humidity, while the dry temperature decreases [3-8]. On the other hand, the relative humidity of the product decreases, and the dry temperature increases. To illustrate the transfer of heat and mass that take place, characteristic graphs of drying are drawn which represent the variations of

- The water content depending on the time,

$$X_r = X_r(t)\,.$$

- -The amount of water evaporated depending on the time.
- The variation of the product temperature during the drying process, *T(t)*.
- The drying speed depending on time, *dX/dt=dX/dt=f(t)*

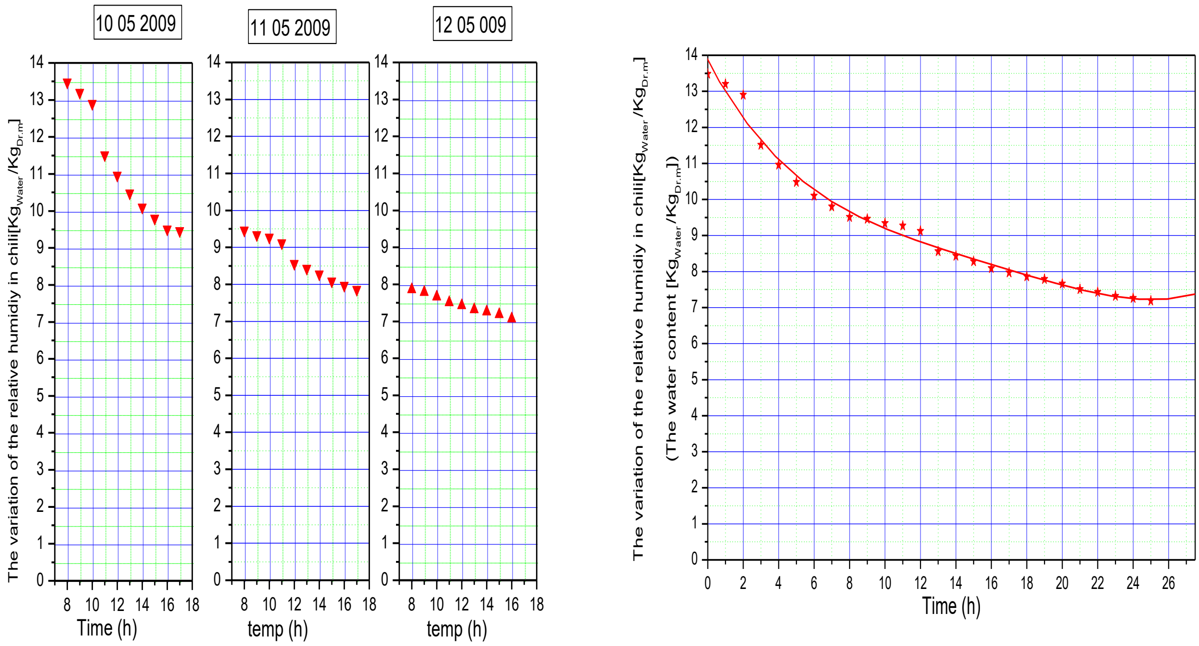

Figure 4: Variation In Water Content Depending on The Time

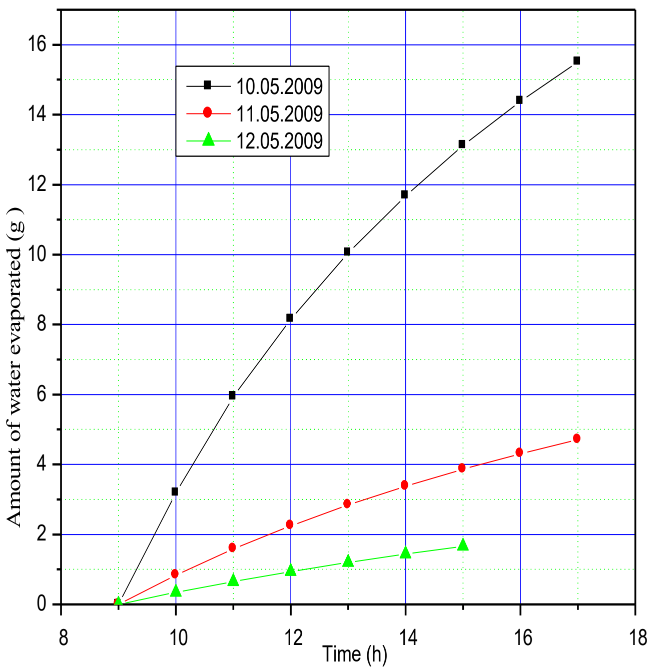

Figure 5: Amount of Water Evaporated During the Drying of Pepper during Three Successive Days

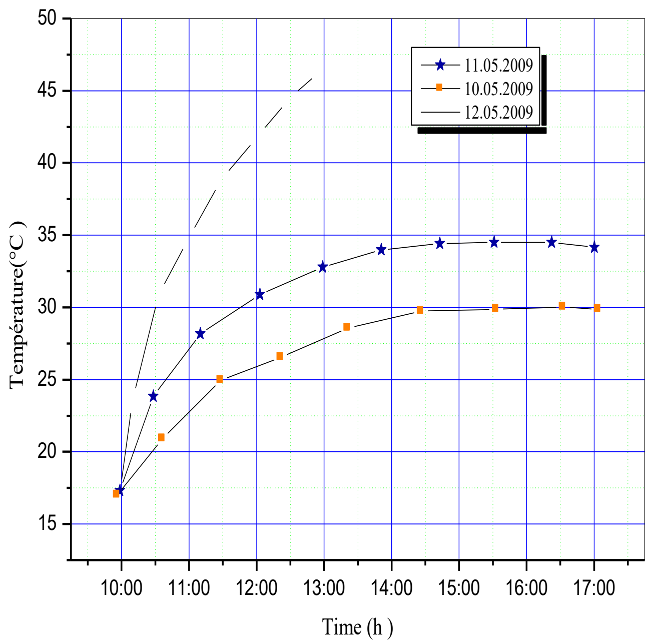

Figure 6: Variation of Product Temperature during Drying

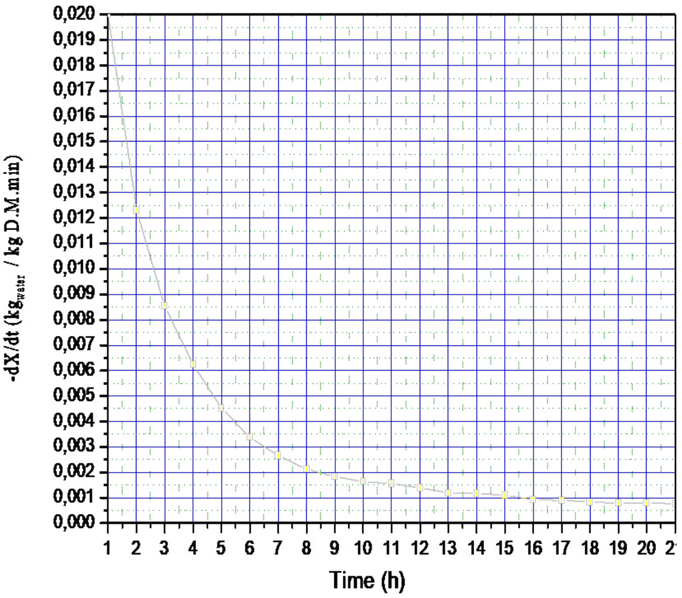

Figure 7: Drying Speed of Pepper during Three Successive Days

For the first day, we notice in figure (4) a decrease from 13.48 to 9.46 (*Kg water. kg ms*$^{-1}$)) which corresponds to 29.83 % of the initial humidity, which explains the evaporation of a significant amount of water representing a mass of 15.50637 g in figure (4). On the second day the decrease of Xr is less important, it varies from 9.46 to 7.86 (*Kg water. kg ms*$^{-1}$)) , and the amount of water evaporated is 4.71003 g, and finally, for the 3rd day, the graph of the water content is quite uniform, the amount of water evaporated during this period is low (1.66655 g) [9, 10].

After the three days of drying the final content obtained is: X_f =7,07.

In figure (5) it can be seen that there is a significant increase in the amount of water evaporated depending on time in the first day (10-05-2009) compared to the other two days (11 and 12-05-2009), because the water content in the green pepper at the beginning of the drying process is higher than on the other two days.

Figure (6) shows the variation of the temperature of the product to be dried for the three days of drying; the maximum values of temperatures are respectively 33, 37, and 46 °C. It can be seen that the highest temperatures are obtained on the third day when the water content is minimal [11-14]. This result is seen when the water content decreases as its temperature increases.

In figure (7) we notice the unique presence of phase 3 which is the drying phase with decreasing speed, or the slowing down phase, and the absence of phases 1 and 2 which are respectively, the period of temperature setting, and the period with constant speed, it means that the speed of drying is controlled by the diffusion of water from the inside of the product towards its surface [15, 16].

Conclusions

Solar drying is an economic method for the valorization of agro-alimentary products and medicinal plants; it allows conserving the nutritional elements of the product.

Indirect solar dryers with natural convection are well adapted to this type of drying, especially in arid and semi-arid regions, which have a large solar resource.

In our work, during the drying operation, we have respected the final content of the products, which is 7.07% for the pepper [17-19]. This is the optimal value for which the product does not deteriorate and keeps its nutritional qualities; color, taste, smell and essential oils, etc.

Abbreviations

X Water content of the dry product, *[Kgwater.Kg (Ms)*$^{-1}$].
X_r Water content of the wet basis product, *[Kg water. Kg (Mh)*$^{-1}$*]*.
M_s Dry mass of the product, *[Kg]*.
M_h Wet mass of the product, *[Kg]*.
dX/dt Drying speed of the product, *[Kg water.(Kg (MS).s)*$^{-1}$*]*.
H_r Relative humidity, [%].
H_a Absolute humidity, *[Kg water.Kg (as)*$^{-1}$*]*.
H_r Relative humidity, *[Kg water .Kg (as)*$^{-1}$*]*.
P_s Saturation pressure, *[Pa]*.
P Total pressure, *[Pa]*.
P_v : Partial pressure of water vapor, *[Pa]*.

Declarations

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable

Competing Interests

I declare that the authors have no competing interests as or other interests that might be perceived to influence the results and/or discussion reported in this paper.

Author Contributions

The corresponding author (Nacer. Chouchane) did the experimental study, obtained, analyzed the results, and prepared all figures.

The other authors (Hammam. Chouchane, Hatem. Houhou, and Ahmed. Fergeni) wrote and organized the article.

All authors reviewed the manuscript

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Not applicable

Availability of Data and Materials

The data that support the findings of this study are available on request from the corresponding author, N.Chouchane. The data are not publicly available due to their containing information that could be stolen or used by non-authorized persons.

The authors confirm that the supplementary materials supporting the findings of this study are available at the Laboratory of Civil Engineering, Hydraulics, Sustainable Development and Environment (LAR-GHYDE), University Mohamed Khider-Biskra 07000, Algeria.

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