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A modeling study for moisture diffusivities and moisture transfer coefficients in drying of passion fruit peel

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ABSTRACT

In the present work, the mass transfer characteristics, namely moisture diffusivity and moisture transfer coefficient, of passion fruit peel were evaluated using the analytical model proposed by Dincer and Dost. Passion fruit peels were dried in a single layer at different temperatures (50, 60, and 70 °C) and air velocities (2.0 and 3.5 m/s). The results showed a reasonably good agreement between the values predicted from the correlation and the experimental observations. The Biot number, effective moisture diffusivity, and mass transfer coefficient were computed and ranged between 0.1018 and 0.3199, 0.632×10^{-8} and 1.994×10^{-8} m^2/s, and 4.53×10^{-7} and 8.702×10^{-7} m/s, respectively.

1. Introduction

Passion fruit (*Passiflora edulis*) is an exotic fruit with a characteristic flavor. It is native of Brazil, the largest producer of this species in the world with a yearly nationwide production of around 750 thousand tons [1] is widely cultivated, mainly for the use of its pulp in the food industry (processed juices, soft drinks, and candies) [2]. The waste generated during passion fruit processing consists mainly of peels and seeds that are discarded as agro-waste [2–4]. Passion fruit peel (mesocarp) corresponds to approximately 50% of the fresh fruit's weight [5]. Several studies have pointed out the significant amount of pectin in the passion fruit's mesocarp and how it could be converted into products which may have positive health effects and contribute to preventing some diseases such as cancer, cardiovascular diseases, and diabetes, among others, thus offering a great opportunity for using such waste [3,6–8]. However, a high percentage of passion fruit peel is water (approximately 80% in weight), and, if improperly handled, is quickly perishable since it is prone to rapid microbial spoilage. Therefore, before pectin extraction from passion fruit peel, its moisture content must be reduced to such extent that prevents microorganism growth. Drying is important in pectin production in order to guarantee the moisture needed for better product extraction without negatively affecting the material [9–12].

Convective drying is defined as a moisture removal process simultaneously using heat and mass transfer. Heat is transferred by convection from heated air into the product to raise the temperatures of both the solid and moisture content. Moisture transfer occurs as the moisture travels to the product's evaporative surface and then into the circulating air as water vapor. The heat and moisture transfer rates are, therefore, related to the velocity and temperature of the circulating drying air. It is also one of the most often used methods to preserve agricultural products.

One of the major concerns in the drying process is providing optimum conditions for quality products, which can be obtained by analyzing the moisture transfer and moisture transfer parameters in terms of moisture diffusivity and moisture transfer coefficient. Accurately determining moisture transfer parameters is important in order to obtain quality dried products and leads to a more energy-efficient drying process, which eases the environmental impact in terms of pollutants [13–15].

Food and biomaterial drying is a very broad area and many experimental and theoretical investigations are found in the literature to determine and estimate drying process parameters and drying moisture transfer parameters for drying solids [16–19].

For better control over this operation, accurate models must be employed to simulate the drying curves under different conditions. Several complex heat and mass transfer models have been developed for various foodstuffs. However, practical drying requires simple models verified by experimental data that will provide optimum solutions for the operating process without undertaking experimental trials on the actual system.

In the drying of many food products, the most widely investigated theoretical drying model has been Fick's second law of diffusion. Such law can be used for various regularly shaped bodies such as

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Nomenclature

D	moisture diffusivity (m^2/s)
t	time (s)
W	moisture content by weight (kg/kg)
A_1	constant
B_1	constant
B_i	Biot number
F_o	Fourier number
S	drying coefficient (1/s)
Y	characteristics dimension
y	coordinate
h_m	moisture transfer coefficient (m/s)
R	universal gas constant
Ea	activation energy
T	temperature (°C)
G	lag factor
k	moisture transfer coefficient (m/s)
R^2	coefficient of determination
L	characteristic dimension (m); half-thickness for slab (m)
z	coordinate

Greek symbols

Φ	dimensionless moisture content
μ_1	root of the characteristic equation

Subscripts

e	equilibrium
i	initial
abs	absolute
0	value for an infinite
exp	experimental

rectangular, cylindrical, and spherical products and it commonly postulates that one-dimensional moisture movement takes place with constant diffusivity, uniform initial moisture distribution, negligible external resistance, and no volume change.

Dincer and Dost [20,21] developed and verified analytical techniques for characterizing the mass transfer in geometrically and irregularly (by use of a shape factor) shaped objects during drying. New drying parameters, namely drying coefficients and lag factors, were introduced based on an analogy between cooling and drying profiles, both of which exhibit an exponential function over time. The model was applied to slab-shaped wood samples subjected to drying, and the results indicate that the technique was able to accurately determine the moisture diffusivities and moisture transfer coefficients in a simple manner for practical applications, and that it would be beneficial to drying industries [22].

Using the experimental data, the aim of this study is to determine the moisture diffusivity and moisture transfer coefficients for passion fruit peel subjected to convective drying using the analytical model developed by Dincer and Dost [20]. In addition, the effective moisture diffusivity as a function of air-drying temperature is also determined.

2. Materials and methods

2.1. Raw material

Passion fruit by-product was obtained from a fruit pulp manufacturer, located in the city of Castanhal, Pará state, Brazil. The fresh peels were cut into 30 mm-sided, 6.7 ± 0.03 mm-thick slab shapes. The samples were packed in polyethylene bags and placed in a freezer at −20 °C. Before drying, waste samples were thawed for 24 h at 5 °C.

2.2. Drying experiments

The drying process was carried out in a convective tray dryer (Fig. 1) designed and built at the Laboratory of the Faculty of Food Engineering of the Federal University of Para.

Drying experiments, performed in triplicate, were carried out at three commonly used temperatures for biomaterial drying (50, 60, and 70 °C) and two different air flow velocities (2.0 and 3.5 m/s).

Air temperature was regulated by acting directly on the relative on/off relay switch controlling electric heating elements. Air velocity was regulated by controlling the blower motor speed through a frequency modulation device (inverter). Air temperature and velocity were measured using microprocessor thermometers (IMPAC model IP7520, accuracy 0–400 ± 0.01 °C) and a hot-wire anemometer (Instrutherm model TAFR180, accuracy 0.2–20.0 ± 0.1 m/s), respectively. All data collected were recorded using a data logger interfaced to a personal computer.

About 100 g of previously thawed samples were placed as a thin layer in a stainless steel basket, which was suspended on a balance (Ohaus, SP402, USA) with ±0.01 g accuracy. This balance communicated with an interface system (Ohaus, RS232, USA) connected to a personal computer, which recorded and stored the weight changes every 10 min by means of the Microsoft Hyperterminal software until constant weight was reached (equilibrium condition). Initial moisture and equilibrium moisture were determined following the AOAC's No. 934.06 methodology [23], using a vacuum-drying oven (Marconi, MA030, Brazil) and an analytical balance (Shimadzu AY220, Japan) accurate to ±0.0001 g.

2.3. Data analysis

The moisture diffusion process observed during the drying operation is governed by Fick's equation. A number of assumptions were adopted, namely: (i) Thermophysical properties of the solid and the drying medium are constant; (ii) The effect of heat transfer on moisture loss is negligible; (iii) Moisture diffusion occurs in one direction (perpendicularly to the slab surface); and (iv) There are finite internal and external resistances to moisture transfer within the solid. Under these conditions, the transient moisture diffusivity equation in Cartesian coordinates and in dimensionless form can be written as follows [22]:

$$\frac{\partial \Phi}{\partial t} = D\frac{\partial}{\partial y}\left(\frac{\partial \Phi}{\partial y}\right) \tag{1}$$

$$\Phi = \frac{W - W_e}{W_i - W_e} \tag{2}$$

where W is moisture content by weight as dry basis (kg/kg), D is moisture diffusivity (m^2/s), t is time (s), y is the space coordinate measured from the center of the tray, and Φ is the dimensionless moisture content.

Eq. (1) is subjected to the following initial and boundary conditions:

$$\Phi(y, 0) = 1 \tag{3}$$

$$(\partial \Phi(0, t)/\partial z) = 0 \tag{4}$$