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Experimental Evaluation and Modelling for Drying Kinetics of Fruits and Vegetables

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Abstract: *Dehydration operations are important steps in the chemical and food processing industries. Studying the drying kinetics and the drying rate of agricultural products is important in order to minimize energy consumption and, accordingly, the cost of the drying process by determining the optimum drying conditions. under optimized drying conditions and temperature, drying can also enhance the product quality. It is important to understand the basic idea of modeling the drying kinetics of fruits and vegetables. The drying kinetics models are significant in deciding the ideal drying conditions, which are important parameters in terms of equipment design, optimization, and product quality improvement Modeling the drying kinetics of fruits and vegetables are two very important areas of drying.*

Keywords: *Drying kinetics, modeling, fruits, vegetables, storage.*

1. INTRODUCTION

Process modeling is of great significance in the analysis of design and optimization of dryers. The most essential pan of process model development involves determination of the drying kinetics, which describe the mechanisms and the influence that certain process variables exert on moisture removal processes. The more frequently encountered phenomenon in the modelling of drying operations, is moisture transfer. Drying is one of the oldest and a very important unit operation, it involves the application of heat to a material which results in the transfer of moisture within the material to its surface and then water removal from the material to the atmosphere (Ekechukwu 1999; Akpinar and Bicer 2005). It is the most frequent method of food preservation and thereby increases shelf-life and improves product quality. The frequent application of drying in the food, agricultural, manufacturing, paper, polymer, chemical, and pharmaceutical industries for different purposes cannot be overemphasized. In addition to preservation, the reduction in the bulk and weight of dried products reduces handling, packaging, and transportation costs. According to Klemes and others (2008), there are over 200 dryer types which can be used for different purposes. Also, the drying features for pressure, air velocity, relative humidity, and product retention time vary according to the material and method of drying.

Dehydration operations are important steps in the chemical and food processing industries. The basic objective in drying food products is the removal of water in the solids up to a certain level, at which microbial spoilage and deterioration chemical reactions are greatly minimized. The wide variety of dehydrated foods, which today are available to the consumer and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process.

Conventional air-drying is the most frequently used dehydration operation in food and chemical industry. In this case, the drying kinetics is greatly affected by air temperature and material characteristic dimension, while all other process factors exert practically negligible influence (Kiranoudis et al., 1997). Dried products are characterized by low porosity and high apparent density (Krokida and Maroulis, 1997). Significant color changes occur during air drying (Krokida et al., 1998), and most frequently the dried product has low sorption capacity (Maroulis et al., 1988).

Over time, the models developed have been used in calculations involving the design and construction of new drying systems, optimization of the drying process, and the description of the entire drying behavior including the combined macroscopic and microscopic medium of heat and mass transfer.

Thus, it is important to understand the basic idea of modeling the drying kinetics of fruits and vegetables. The drying conditions, type of dryer, and the characteristics of the material to be dried all have an influence on drying kinetics. The drying kinetics models are therefore significant in deciding the ideal drying conditions, which are important parameters in terms of equipment design, optimization, and product quality improvement (Giri and Prasad 2007). So, to analyze the drying behavior of fruits and vegetables it is important to study the kinetics model of each particular product. The objective of this work is to investigate the drying kinetics of some fruits and vegetables. These fruits and vegetables are of particular interest in preparation of various food items. More specifically the aim of this work was to study the effect of some drying parameters on the progress of the drying process.

2. MATERIALS AND METHOD

The empirical models chosen to describe moisture transfer within the fruits dried, can take the form of a general linear ordinary differential equation, in which the righthand side contains an empirical mass transfer coefficient multiplied by the corresponding driving force. In this study, the suggested empirical model takes the form of the following equation:

$$dXs/dt= kM (Xs-XSE)$$

where XS is the material moisture content. XSE is the equilibrium material moisture content and kM is the drying constant. The latter is determined by the slope of the falling rate drying curve.

When the drying conditions remain constant, this model has analytical solution, in exponential form. In this equation, the equilibrium moisture content of vegetables is presented in the form of the well-known GAB equation, which is the one that best represents the equilibrium moisture isotherms of desorption (Carbonell et al., 1986; Maroulis et al., 1988; Samaniego-Esquerra et al., 1991):

$$XSE= XMCKaw/[(1-Kaw)\,(1-Kaw+CKaw)]$$

where aw is the water activity of surrounding air. XM is the monolayer material moisture content, while C and K are related to temperature. That is:

$$C= C_0\exp(\triangle H_C/T)$$

$$K = K_0\exp(\triangle H_K/T)$$

where T is the absolute temperature of the surrounding air, $\triangle H_C$ and $\triangle H_K$ are functions of heat of sorption of water (mono and multimolecular layers) and heat of condensation of water vapor (Maroulis et al., 1988). The effect of other process variables can be embodied in the expression of the phenomenological parameters involved improving in this way the goodness of model fit to the experimental data. The most relevant expression for the correlation sought, can be presented in the form of the following empirical equation:

$$kM = k_0dp^{k1}T^{k2}V^{k3}aw^{k4}$$

where dp is the characteristic particle dimension, T is the drying air temperature, V is the superficial velocity of drying air and aw is its corresponding water activity. In this expression, the empirical coefficients ki, i=0,..,4 can be estimated by fitting the total model employed to the experimental drying curves. In the case of one-response problems, the most frequently used method for estimating the parameters of a model is by minimizing the mean standard deviation between experimental and calculated values:

$$S2R = \sum_{i=1}^{N} ei2/N$$

where ei is the residual created when comparing the model calculations with experimental observation i, and N is the number of the residuals produced. This comparison refers to each experimental point, regardless its position in a specific experiment (direct regression). Such an analysis can produce final parameter estimates without intermediate correlations. The mean standard deviation for each individual experiment is given by the following equation:

$$S2R = \sum_{k=1}^{nj} e2K/nj$$

where nj is the number of experimental points obtained during experiment j.

The regression method used in this study in order to estimate the best model parameters was the non-linear method of Levenberg-Marquard in the form of the algorithm of subroutine ZXSSQ/MSL.

Fresh fruits and vegetables were used. The samples were dehydrated in an experimental airdryer, which consists of four basic sections: air flow rate control, heating control, humidity control and drying test compartments. Experiments to determine the influence of process variables on the drying kinetics were performed

3. RESULTS AND DISCUSSION

The parameters of the proposed model (constants k0, k1, k2, k3 and k4) for prediction of the drying constant k are given in Table 1 (Panel A). These parameters resulted from an optimization technique to minimize the mean standard deviation between experimental and calculated values of moisture content.

Drying Kinetics

The empirical model under consideration was applied to the experimental data. The drying constant determined, embodies all process variables examined by means of the five-parameter empirical equation (4). The application of non-linear regression analysis on the experimental data, gave the results shown on Table 4. The mean standard deviation between experimental and predicted values, for all fruits examined is also presented on Table-1.

Results of the regression analysis of drying kinetics

Fruit	K_0 (h^{-1})	K_1	K_2	K_3	K_4	S_R(%)
Apple	1.1×10^{-5}	-1.37	1.43	0.16	- 0.27	28.6
Mango	7.1×10^{-6}	-1.28	1.61	0.15	0.009	21.5
Kiwi	6.2×10^{-6}	- 1.39	1.47	0.22	0.005	22.6
Green Pea	6.6×10^{-5}	- 1.09	0.98	0.11	0.001	20.4
Mushroom	4.8×10^{-4}	-1.16	1.20	0.24	-0.18	31.3

Fruits and vegetables are highly perishable commodities that need to be preserved to increase shelf-life. The drying process can be predicted using suitable thin-layer models. Several researchers have studied the drying of fruits and vegetables using thin-layer drying models to estimate the drying time of a product (Meisami-asl and Rafiee 2009; Gupta and Alam 2014; Tzempelikos and others 2015). Evidence suggests that these models can further be used to estimate the drying curve and also predict the drying behavior, energy consumption, and heat and mass transfer of the drying process (Murthy and Manohar 2012). However, in practice, there is no single thin-layer model that can be used to effectively generalize the drying kinetics of several fruits and vegetables. This is due to a number of factors including the method of drying, the drying conditions, and the product to be dried. The application of thin-layer drying models to predicting the drying behavior of fruits and vegetables often involves the measurement of the moisture content of the material. This is done after it has been subjected to different drying conditions (temperature, air velocity, and relative humidity) and subsequent correlation with the dominant drying condition to estimate the model parameters. Incorrect collection of experimental data from the thin-layer drying experiments, will affect the drying process and, subsequently, the selection of appropriate thin-layer models.

Another important reason behind drying vegetables and fruits is to facilitate transportation and storage. Fresh raw fruits and vegetables are not easy to transport. However, drying these agricultural products under appropriate conditions makes the transportation process significantly easier without losing a noticeable amount of contained vitamins (Sagar and Kumar, 2010). Drying also prevents microbial contamination by reducing the water activity of the fresh agricultural commodities (Pal et al., 2008). In the presence of moisture, pathogens can colonize the fruits and vegetables, producing mycotoxins that possess a health hazard to consumers (Akeredolu and Adebajo, 2013). Furthermore, under optimized drying conditions and temperature, drying can also enhance the product quality.

4. CONCLUSION

Studying the drying kinetics and the drying rate of agricultural products is important in order to minimize energy consumption and, accordingly, the cost of the drying process by determining the optimum drying conditions. Modeling the drying kinetics of fruits and vegetables are two very important areas of drying. However, most production losses in the industry occur during drying. In order to minimize these losses it is necessary to optimize the drying conditions, machine design, and product quality. There is a need to identify and evaluate the drying mechanisms, theories, applications.

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