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Prediction of Water Loss During Potato Vacuum Frying Process

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Abstract

Vacuum frying may be a good alternative for the production of dehydrated fruit and vegetable slices. In this study, a relationship between water losses with frying time during vacuum frying process of potato chips has been developed. A first order kinetic model was used, in which drying rate constant is a function of the main process variables, i.e. oil temperature, sample thickness and vacuum pressure. The experimental data of Garayo and Moreira (2000) have been used to validate the model. Generally there was a good agreement between the calculated results and the experimental data. Then, the effect of initial water content and vacuum pressure has been studied.

Keywords: kinetic model, potato, vacuum frying, water loss

1. Introduction

Frying is an established process of food preparation world-wide. It is a simultaneous heat and mass transfer process where moisture leaves the food in the form of vapor bubbles, while oil is absorbed simultaneously. During the frying process, the physical and chemical characteristics of the food are modified.

To date most of the research has been related to conventional deep-fat frying under atmospheric pressure. However, deep-fat frying is performed at a high temperature of about 180^{o}C under atmospheric pressure. Because of the higher heat treatment, surface darkening and many other adverse reactions may occur before the food is fully cooked. Vacuum frying is an alternative way to improve the quality of dehydrated food. The sample is heated under a negative pressure that lowers the boiling points of the frying oil and the water in the food. Moreover, the absence of air during frying may inhibit oxidation including lipid oxidation, enzymatic browning and, therefore, the color and nutrients of samples can be largely preserved (Xu, 1996; Fan *et al*., 2005). The color and flavor can be better preserved in vacuum-fried food, because the food is heated at lower frying oil temperature and oxygen content. Dehydrated food produced by vacuum frying can thus have many characteristics improvement such as more crispy texture, good color and flavor and good retention of nutrients. Vacuum frying also has less adverse effects on oil quality.

Several models have been developed to describe moisture evaporation and oil absorption in deep-fat frying (Moreira and Arkema, 1989; Rice and Gamble, 1989). Mittelman *et al*. (1984) reported that oil temperature and frying time are the main frying operation variables controlling mass transfer in deep-fat frying. However, most of the research found in the literature is related to atmospheric frying.

The objective of this study was to examine water loss phenomena during vacuum frying of potato chips. Potato (*Solanum tuberosum*) is one of the world's major agricultural crops and it is consumed daily by millions of people from diverse cultural backgrounds. The aim of this work was not to study the mechanism of water loss but to examine the relationship between moisture loss with frying time. The effect of the main process variables, i.e., frying oil temperature, initial water content and vacuum pressure in the frying medium were studied and a kinetic model was developed. In this study, the experimental data of Garayo and Moreira (2000) have been used to validate the kinetic model developed.

2. Methodology

The potatoes were taken out of storage at least 12 h before frying to let them reach room temperature and for the reducing sugar contents to decrease. Once the potatoes were peeled and sliced, they were soaked in water for a few seconds, and then dried in paper towels prior to frying. About 5–6 slices of potatoes (20 to 25 g) were fried each time. Once the oil temperature reached the target value, the potatoes were then placed into the basket, the lid closed, the vessel evacuated. At this moment, the basket was lowered to the oil and frying began for the desired frying time. Once the potato slices were fried, the basket was lifted from the oil and the vessel pressurized. The potato chips were fried until the equilibrium moisture content was reached. Then, the lid of the vessel was opened and the potato chips were removed from the basket. The potato chips were then allowed to cool to room temperature, dried with paper towel, and later stored in polyethylene bags for further analysis. Three levels of oil temperature (118°C, 132°C, and 144°C) were considered in this study. Garayo and Moreira (2002) explained a more detail of the vacuum frying experiments.

3. Mathematical Model and Solution Method

A first order kinetic model describing the moisture transfer during frying is considered (Krokida *et al.*, 2000):

$$-\frac{dX}{dt} = K_X\left(X - X_e\right) \tag{1}$$

where, X is the material moisture content (dry basis) during frying (kg water/kg dry solids), X_e, is the equilibrium moisture content of dehydrated material (kg water/kg dry solids), K_X is the drying rate (min^{-1}), and t is the time of frying (min). It is based on the following assumptions: (1) the oil temperature is constant during frying; (2) initial water concentration in potato strips is uniform; (3) the two flows (water from the potato strips into the oil and oil into the potato strips) were considered to be independent of each other. The equilibrium moisture content of foods (X_e) and rate constant of moisture content kinetics (K_X) can be described by several mathematical models with two or more parameters. However, models having more than three parameters are too complicated for straightforward interpretation or use.

The effect of process variables on mass transfer phenomena during vacuum frying can be embodied into the following empirical equations:

$$X_e = X_{0e}\left[\frac{T}{170}\right]^{X_T}\left[\frac{P}{P_{\max}}\right]^{X_P}\left[\frac{d}{10}\right]^{X_d} \tag{2}$$

$$K_X = K_{0X}\left[\frac{T}{170}\right]^{K_{XT}}\left[\frac{P}{P_{\max}}\right]^{K_{XP}}\left[\frac{d}{10}\right]^{K_{Xd}} \tag{3}$$

where T is the frying oil temperature (°C), d is the cross-section thickness of the sample (mm), P is the vacuum pressure of the process (kPa) and Pmax is the maximum vacuum pressure (kPa) used in the experiments. The experimental data on water content present at any time versus the frying time of Garayo and Moreira (2002) were fitted to the solution of Equations (1), (2) and (3). Equations (2) and (3) were developed for application to the vacuum frying process with a small modification of the correlation previously developed for the conventional deep-fat frying process by Krokida et al. (2000).

The estimation of the above 8 parameters (K_{0X}, K_{XT}, K_{Xd}, K_{XC}, X_{0e}, X_T, X_d, X_C) was carried out using a non-linear regression analysis method

The model parameters are estimated by directly minimizing the mean standard deviation between experimental and calculated values:

$$S^2 = \frac{\sum_{i=1}^{N}(X_{i,calc} - X_{i,\exp})/X_{i,\exp}}{N} \tag{4}$$

where, $X_{i,calc}$ is the model fitted value which corresponds to the experimental observation $X_{i,exp}$ and N is the number of residuals produced. This form of residuals is based on relative errors between experimental and calculated values, and accounts for data with different orders of magnitude.

4. Results and Discussion

Figure 1 represent the drying curves for vacuum frying at various temperatures. The experimental data of Garayo and Moreira (2002) also shown as comparison. As can been seen in Fig. 1, the loss of moisture during frying exhibited a classical drying profile. The drying process of foods is generally characterized by three distinct periods. The first is an initial heat-up period during which the wet solid material absorbs heat from the surrounding media. The product is heated up from its initial temperature to a temperature where the moisture begins to evaporate from the food. In vacuum frying, this initial heat-up period is very short and therefore difficult to quantify. At a vacuum pressure of 3.115 kPa, for example, the boiling point of water is around 25°C. The temperature in the potato slice is slightly higher than the boiling point of water due to the presence of some solutes. Since the temperature of the potato slices prior to frying was at room temperature (23–24°C), the slices only had to warm up a few degrees for the water to start boiling.

The second drying period is known as the constant rate period. Here, the rate of drying is limited by the rate at which heat is transferred from the drying medium to the product. The constant drying conditions continue as long as the food surface remains wetted with water. In the case of potato chips fried under vacuum frying, there was no constant rate period.

When the moisture level in the product is so low that its surface is no longer wetted, the drying rate entering the falling rate period decreases. During this period, drying rate is controlled by moisture diffusion mechanisms. The water during this period is held in the material by multi-molecular adsorption and capillary condensation.

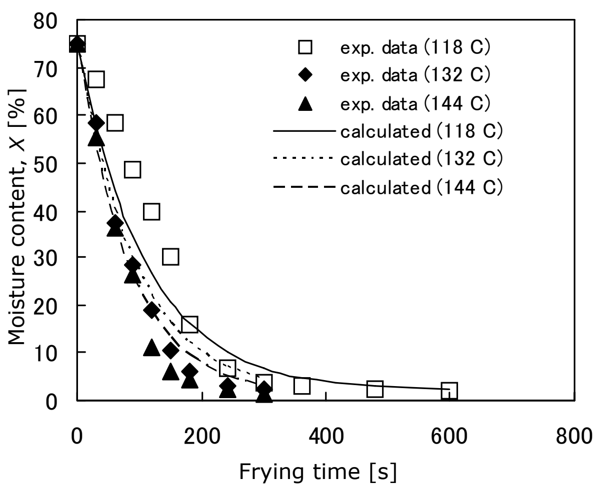

Figure 1. Moisture content as function of frying time for various oil temperatures at vacuum pressure 9.88 kPa.

Figure 1 also shows that potato chips fried at an oil temperature 144°C took the shortest time to fry at about 360 s. Potato chips fried at the same pressure and at 132°C and 118°C, took about 480 s and 600 s to fry, respectively. Decreasing the oil temperature increased the frying time of potato chips fried under vacuum as expected.

As previously pointed out by Fan *et al.* (2005), loss of moisture during vacuum frying was similar to the falling rate period of drying. Increasing of the oil temperature at the same vacuum pressure decreased the frying time of potato chips and improved the rate of drying. Frying temperature significantly affected the moisture content. The higher the temperature, the lower the moisture content. The similar trend results were observed in the present experimental data and calculated result. However, the result trend was not in agreement with the work of Sulaeman *et al.* (2001). They reported that the higher the temperature, the higher the moisture content during deep-fat frying of carrot chips.

One of major difference between potato slices fried under vacuum and atmospheric conditions is the surface structure of the potato chips formed during the frying process. Some visual observations indicated that the surface of a vacuum fried potato chip had less expansion and numerous small bubbles, as opposed to a potato chip fried under atmospheric pressure, which showed more expansion and lesser but larger bubbles.

The bubble formation at the product's surface is the results of gas expansion inside the pores. For the vacuum fried chips, once the fryer is evacuated, the water vapor in the pores expands with little resistance even before the product is fried. During frying, little expansion may be produced by the superheated vapor trying to escape the pore space. For the chips fried under atmospheric conditions, the expansion happens when the product is immersed in the oil. Water is heated first and then the vapor expanded. As a result, large, but few, bubbles will be formed at the chips surface.

Process simulation has been carried out to study various process conditions such as initial moisture content and vacuum pressure. The simulation result has been presented in Figures 2 and 3.

Figure 2 shows the effect of initial moisture content for potato chips fried at a temperature of 118^{o}C. As expected, it took longer time for the chips to reach the same final moisture content by increasing the initial moisture content. It is also observed that there is no significant difference of final moisture content for initial moisture content variation.

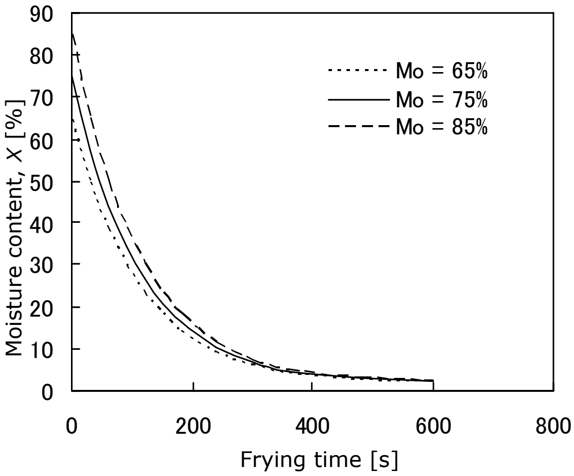

Figure 2. Effect of initial moisture content for oil temperature 118^{o}C and vacuum pressure 9.89 kPa

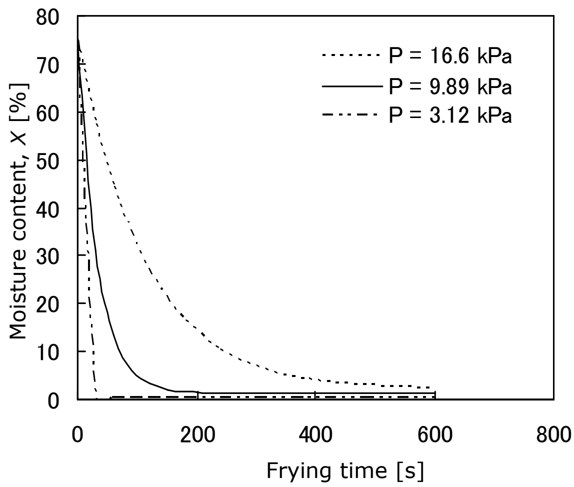

Figure 3. Effect of vacuum pressure for oil temperature 118^{o}C and initial moisture content 75%

Figure 3 shows the effect of vacuum pressure on moisture content history for potato chips fried at a temperature of 118°C. Figure 3 shows that there is a negative correlation between vacuum pressure and moisture loss rate for the same oil temperature. This is due to the fact that the more the pressure is lowered; the further the boiling point of water is reduced. As a consequence, the water in the potato chips will begin to vaporize faster at a higher vacuum level. It also shows that by decreasing the vacuum pressure, for a fixed value of temperature, it took less time for the chips to reach the same final moisture content. The same trend result has been reported by Fan *et al.* (2005) and Krokida *et al.* (2000).

5. Conclusions

A first order kinetic model describing the relationship between water losses and frying time for vacuum frying process has been developed in this study. The model has been applied for vacuum fried of potato chips. Generally, there was a good agreement between the calculated results and the experimental data available in the literature. Based on the simulation results, the effect of initial moisture content and vacuum pressure on the time of frying process has been studied.

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