STUDY OF CONVECTIVE DRYING APLLE SLICES KINETICS.
EFFECT ON SHRINKAGE.

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***Abstract.*** *Drying rate is controlled by different factors that change during the drying process. The time of the process and energy costs can be reduced using variable conditions. Therefore, the influence of different air conditions on the drying rate has been analysed in this work. It was found that shrinkage depends only on the material humidity content.*

***Keey-word:*** *Drying kinectics, Aplle slices, Shrinkage*

## 1. INTRODUCTION

Dehydration involves simultaneous transfer of heat, mass and momentum. Heat penetrates into the product and moisture is removed into an insaturated gas phase. Due to the complexity of the process, there is not a generalized theory to explain the mechanism of internal moisture movement (Rizvi, 1986).

The factors that control the drying rate in the constant-rate and falling-rate periods are differents. At the constant-rate period, the factors that control the process are the temperature, velocity and relative humidity of the air. At the falling-rate period, these factors are the air temperature and the material thickness, while the air velocity and relative humidity don't affect the drying rate (Rizvi, 1986; Fellows, 1988). So drying variable conditions can be used with the purpose of reduction the drying total time and its energy costs.

Shrinkage is one of the main factors that depreciate the food during the drying process. It takes place while the water is been lost and, somehow, it may have influence over the drying rate. The study of shrinkage phenomenon is, in this sense, important to the better understanding of the drying process (Rovedo et al., 1995). The use of a drying initial stage at a high temperature and short time (HTST) in fluidized bed has been used in the dehydration of fruits and vegetables to prevent shrinkage. This stage can promote the puffing of many materials. It can also reduce the drying time. Dried products have low density and high rehydration rate (Kim e Toledo, 1987).

This report studies the influence of different air drying temperatures and velocities on the drying kinectics of apple slices. It was also observed the material shrinkage development during the process.

## 2. MATERIALS AND METHODS

### 2.1 Raw materials

Fuji cultivar apples were purchased locally and cold-stored until used. The apples were halved, takenout the seeds and cut into slices with 5,8 mm of thickness.

### 2.2 Drying process

Two drying process were used for the experiments: a) conventional drying at moderated air temperatures; b) conventional drying preceded by the HTST (high temperature and short time) process.

Air temperatures of 120°C or 140°C during 15 minutes, were used in the HTST process and after decreased to 60°C or 80°C. Conventional drying uses temperatures of 60°C, 70°C and 80°C. Air velocities of 1,5, 3,0 and 6,0 m/s were used in both processes. Other drying conditions are shown elsewhere (Schultz e Quadri, 1999).

### 2.3 Analyses

The water content of apples (raw and dried) was determined in a mechanical convection oven at 75°C for 48 h, or until constante weight was attaingned. The apparent density used in the calculation of the material shrinkage was determined by measuring the volume of the sample by toluene displacement. Duplicated measurements were developed.

### 2.4 Drying kinectics

The apple slices used for determining drying curves were put on a tray that was weighted periodically during the drying process, to measure the loss of water. A software using the method of geometric derivation (Quadri, 1998) was apllied to calculate drying kinetics.

### 2.5 Volume of the Apple Slices during the Drying

Density and moisture of the material can be related, during the shrinkage, through a mass balance. The change of the volume, or shrinkage, during the drying, can be related with the density and moisture of the material through a dry fibre mass balance (Perez and Calvelo, 1995):

$$\frac{V}{V_0} = \frac{\rho_0(1+X)}{\rho(1+X_0)} \tag{1}$$

where $V_0$ and V are the volumes of the apple slices ($m^3$), $\rho_0$ and $\rho$ the density of these apple slices (kg $m^{-3}$) and $X_0$ and X the moisture content of the apples (kg water/kg dry material) at the beginning of the process and at time t, respectively.

## 3. RESULTS AND DISCUSSION

The influence of the air temperature is illustrate on Figure 1. The curves were obtained at 60°C, 70°C and 80°C. Some drying experiments at 60°C and 80°C were preceded by HTST process at 120°C or 140°C during 15 min. The air velocity used was 3 m/s.

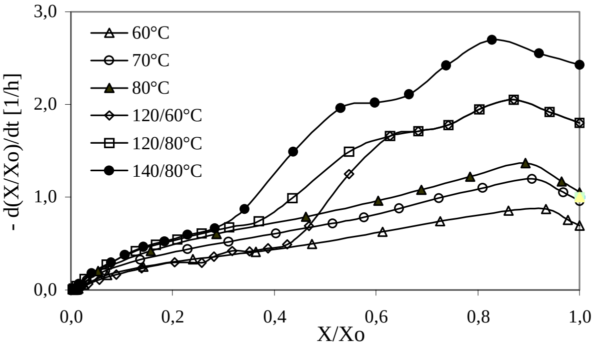


Figure 1 - Apple slices drying kinetics at differente tamperatures at 3 m/s.

As shown the experiment at 60°C has the lower drying rate through all the drying process. At lower temperatures (60°C, 70°C and 80°C) the drying rate curves have similar shapes, with an initial period of warming up, followed by a falling-rate period. Constant-rate period wasn't observed in these experiments.

The experiments with HTST periods also showed an initial warming-up period followed by decreasing of the drying rates.These experiments showed three significant changes at the drying rates. The first happens at the HTST period and denotes the passage from the warming-up to the falling-rate periods. The second is represented by the transition between the HTST process and the traditional process. It is important to note that the last point of HTST treatment is represented, in the curves of Figure 1, by the intermediate point between the HTST and tradional temperatures. This behaviour is due to the calculation method of derivatives, where the anterior and posterior points are taked into account for the calculs of one singular point.

It is still possible to see that the drying rate curves HTST period superpose the curves of the experiments made with one and only lower temperature. The third falling-rate period represents the end of the drying process.

The evaluation of the effect of the air velocity on apple drying were made at 1,5, 3,0 and 6,0 m/s, under two conditions: 80°C and 140°C followed by 80°C (Figures 2 and 3).

In the drying kinetics, the intial warming-up period is stronger at lower air velocity, and at 6 m/s this period desappears. Distances between kinetic curves at different velocities decreases as moisture ratio diminishes.

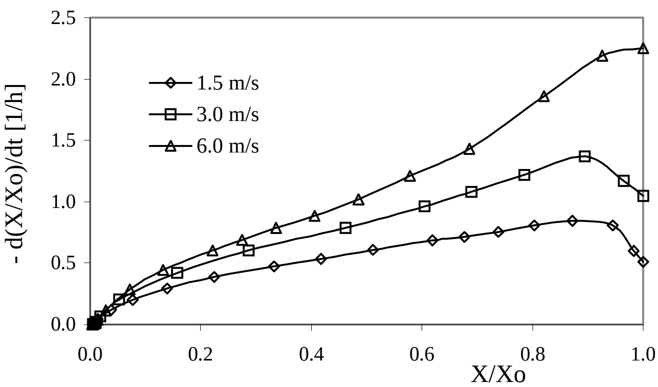


Figure 2 - Drying kinetics at 80°C,at velocities of 1,5, 3,0 and 6,0 m/s.

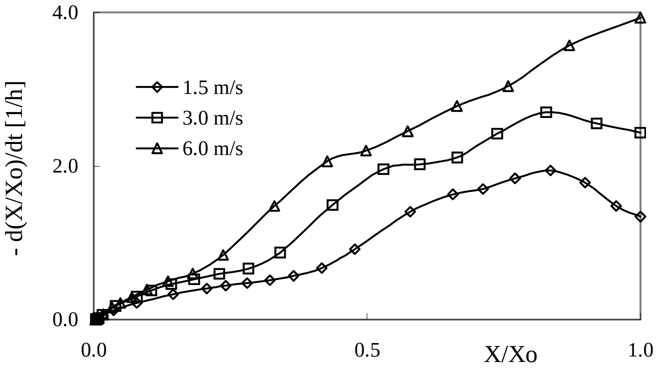


Figure 3 - Drying kinetics at 140°C/80°C,at velocities of 1,5, 3,0 and 6,0 m/s.

Under the conditions of Figure 3, HTST period ends at the values of 0,58, 0,44 and 0,33 for the product's moisture ($X/X_0$), at the velocities of 1,5, 3,0 and 6,0 m/s, respectively. Below these values of $X/X_0$, the drying rate is similar to the three velocities. This shows that drying is most influenced by air velocity at the beginning of the process. The falling rate period shows three significant stages at 1,5 and 3,0 m/s. One of them happens at the HTST stage (Figure 1). The second stage envolves the transition from HTST to the lower temperature and this last one. The third stage ends the drying. The curve at 6 m/s shows a softer transition and doesn't have a warming-up period.

The contraction's volume (shrinkage) of apple slices during drying is illustrated on Figures 4 and 5, for the following drying conditions: 80°C, at 3 and 6 m/s, and 120/80°C, at 6 m/s.

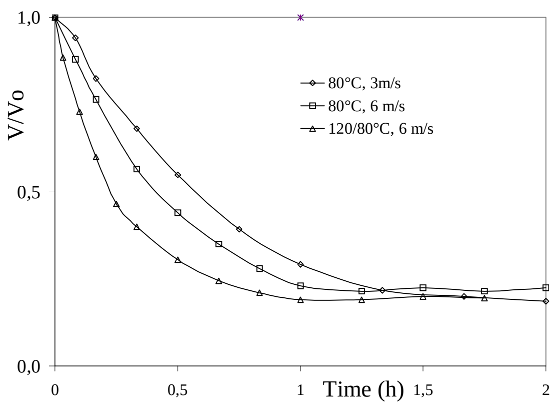


Figure 4. Volume ratio of apple slices as a function of time.

In Figure 4 the curve has the shape of a decreasing exponential curve. The variation of the sample's volume rate is bigger at 120/80°C and smaller at 80°C for air at 3 m/s. In all cases, there is a period of time where the sample shrinks. This period is shorter when the temperature and velocity of the air are higher: at 120°C/80°C at 6 m/s this period is around 50 minutes; for 80°C and 6 m/s, 1 hour, and at 80°C and 3 m/s, 1 hour and 20 minutes.

Otherwise Figure 5 shows three straight lines. They are almost coincident for all experiments. It can be concluded that shrinking depends only on the moisture of the product, drying conditions having no significant effect.

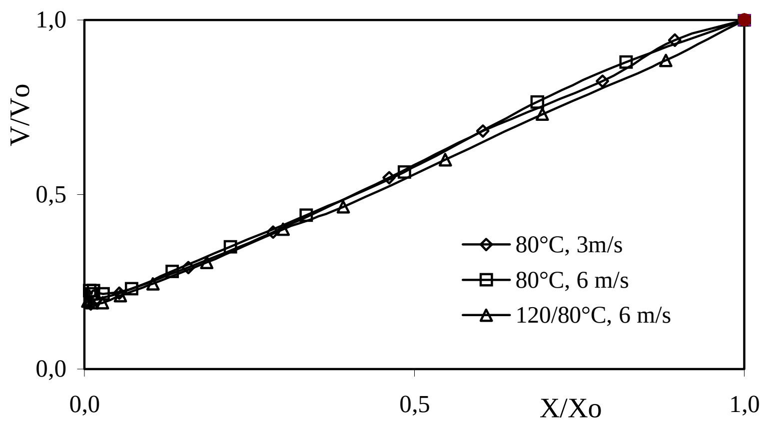


Figure 5. Volume ratio of apple slices as
a function of the moisture ratio.

## 4. CONCLUSIONS

At higher temperatures and velocity of the air the drying rate increases, as expected. Experiments with HTST period showed higher mass transfer rates than experiments without it. After ceased the HTST period, the kinectics acquired the same behaviour of the drying process at lower temperatures (60$^{\circ}$C and 80$^{\circ}$C).

The drying rates of the tests at lower temperatures showed two falling-rate periods. The application of the HTST treatment adds one period at the beggining of the kinectics.

A warming-up period in the drying rates was a constant behaviour for the air velocities at 1,5 and 3 m/s. This was not observed at 6 m/s. The most important influence of the air velocity was at the beginnig of the process when the importance of the mass transfer external resistence is high.

It was found that the volume decreases with the sample's moisture, having no significant differences for the conditions applied.

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