

TECHNICAL NOTE

**INFLUENCE OF DRY MATTER CONTENT AND DRYING CONDITIONS ON
EFFECTIVE DIFFUSION COEFFICIENT OF ONION (*Allium cepa*, L.)**

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ABSTRACT

Demand for fresh and dehydrated onions has increased considerably over the last two decades. To meet this challenge new varieties possessing superior field characteristics have been developed whose dehydration characteristics differ markedly. In this work the influence of dry matter content in the raw onion and drying conditions on the effective diffusion coefficient is studied. In the falling rate period, the diffusion activation energy was found to be 33.9 kJ/mol, and the D_0 parameter (the effective diffusivity at high moisture contents) was found to be $5.0736 \times 10^{-5} \text{ m}^2/\text{s}$. On the basis of measurements with seven different onion varieties (with raw dry matter content between 19.5 and 23.5 kg dry matter/kg fresh product) an exponential relationship was found between the effective diffusivity and dry matter content of the raw onion.

INTRODUCTION

Moisture transfer in foods is a subject of considerable importance in drying food industry today. The mechanisms of moisture transport are numerous and often complex.

Transport phenomena are usually classified as resulting from pressure diffusion, thermal diffusion, forced diffusion, and ordinary or binary diffusion (Van Arsdel, 1963; Rizvi, 1986; Hallström, 1992).

Often a diffusion transport mechanism is assumed and the rate of moisture movement is described by an effective diffusivity value, D_{eff} , no matter the actual mechanism of moisture movement. Even though this method is not quite sound theoretically, it is a practical and convenient approach to describing moisture content change during processing. Parameters required in this approach are only sample dimensions and the effective diffusion coefficient; more complex analyses need permeability, liquid and vapor conductivities, or various phenomenological coefficients which are difficult to determine experimentally (Rizvi, 1986; Rizvi and Mittal, 1992; Okos et al., 1992).

Demand for fresh and dehydrated onions has increased greatly over the last two decades. To meet this challenge many new varieties with superior field characteristics have been developed whose dehydration characteristics differ markedly (Sharma and Nath, 1991). Because of this, several studies on the evaluation of different and new onion cultivars for their suitability for dehydration have been developed (Sharma and Nath, 1991; Gaafar, 1988; Raina et al., 1988; Kalra et al., 1986; Maini et al., 1984; Averina et al., 1974; Averina and Kats, 1974). However, there are few studies of the effective diffusion coefficient of onion and the influence of dry matter content on this coefficient (Kiranoudis et al., 1992a,b; Mazza and Le Maguer, 1980; Saravacos and Charm, 1962).

MATERIALS AND METHODS

The onion varieties used in these studies are *Southport White Globe*, and the *Basic American Vegetables varieties: L56-1566, H85-1211, H64-315, H60-1715, E58-728 and H91-458*. All these varieties are white and globe-form, except the *H60-1715* which has

a spindle form, possessing mean bulb diameter between 6 and 7 cm and different dehydration characteristics (López and Cotonat, 1990).

The onion cultivation practices have been similar for all varieties, but two different sowing times have been considered: 26th January and 11th March (labelled ST 1 and ST 2, respectively), in fields from Lérida (Spain). Table I shows the cultivation yields, the moisture contents, and the root zone diameter values for each variety and the sowing time.

From Table I is found that moisture differences between varieties are more important than those due to different sowing times.

The onion samples were selected, cleaned, hand peeled, de-stemmed, washed and cutted transversely in small discs of 3 mm thickness. The cut onion samples were dried in a cross-flow hot air laboratory drier at different temperatures (60, 70, 75 and 80 °C) and air velocities (0.2, 0.5 and 1 m/s).

Water losses during drying of the onion samples were measured by weighing the basket and their content. The moisture content of the dried product was determined in a vacuum oven according to the procedure outlined by López and Cotonat (1990).

The effective diffusion coefficient was obtained considering the moisture transport to be onedimensional, and product to have a uniform initial moisture content and internal movement as its main resistance to moisture transfer. In this case, the solution of Fick's law for a slab is as follows (Okos et al., 1992):

$$\Gamma = \frac{X - X_c}{X_c - X_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[-(2n+1)^2 \frac{\pi^2 D_{eff} t}{4 L^2}\right] \quad (1)$$

where X is the average moisture content on a dry basis at time t , X_c is the critical

TABLE I. Cultivation yields, moisture contents and root zone diameter values for each onion variety considered.

| Variety | Sowing Time | Yield (kg/ha) | Moisture (% wet basis) | Root zone diameter (cm) |
|----------------|-------------|---------------|------------------------|-------------------------|
| S. White Globe | ST 1 | 17430 | 78.43 | 1.5 |
| L56-1566 | ST 1 | 26500 | 77.35 | 1.5 |
| | ST 2 | 26500 | 77.47 | 1.5 |
| H85-1211 | ST 1 | 8215 | 80.59 | 1.3 |
| | ST 2 | 6777 | 80.26 | 1.5 |
| H64-315 | ST 1 | 9050 | 79.67 | 1.4 |
| | ST 2 | 7466 | 80.48 | 1.5 |
| H60-1715 | ST 1 | 21800 | 79.14 | 1.6 |
| | ST 2 | 20928 | 80.06 | 1.4 |
| E58-728 | ST 1 | 20750 | 77.23 | 1.4 |
| | ST 2 | 19920 | 76.49 | 1.3 |
| H91-458 | ST 2 | 6630 | 86.18 | 1.3 |

moisture, X_e the equilibrium moisture content or surface moisture content, and L is the half-thickness of the slab (m). At sufficiently large times, only the leading term in the series expansion (Eq.1) need be taken. Then, the effective diffusion coefficient are determined by plotting experimental drying data in terms of $\ln \Gamma$ versus time. The slope of the linear segments will yield the effective diffusion coefficient for the falling rate drying period (Rizvi, 1986; Rizvi and Mittal, 1992; Okos et al., 1992).

The dependence of the effective diffusivity on temperature can be described by the Arrhenius equation (Okos et al., 1992):

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (2)$$

where D_{eff} is the effective diffusivity, E_a the diffusion activation energy, and T the

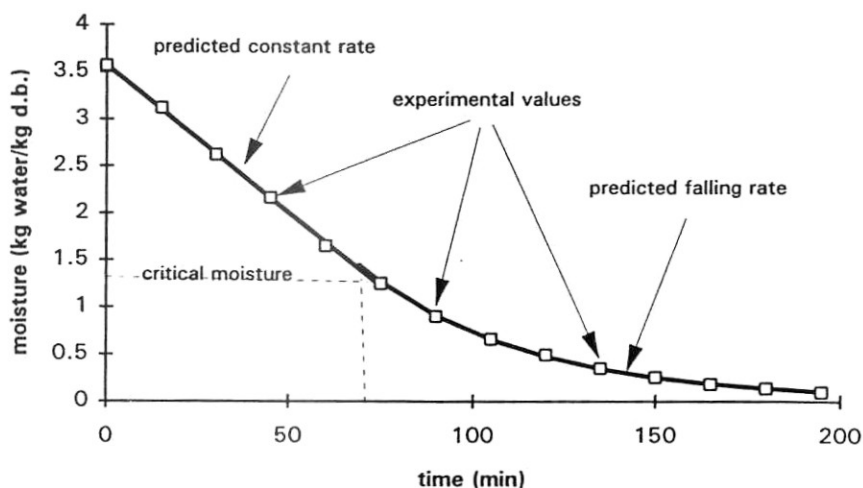


FIGURE 1. Experimental values and fitted constant-rate and falling-rate curves for a thin layer drying experiment of transversely cut onion (variety E58-728) in discs 3 mm thickness.

absolute temperature. The activation energy was determined by plotting $\ln D_{eff}$ versus $1/T$ (Gekas, 1992; Okos et al., 1992).

RESULTS AND DISCUSSION

A typical drying rate curve for an onion drying experiment is shown in Figure 1, where it is possible to see two drying rate periods: the constant-rate period and the falling rate period. To determine the value of X_c the two periods have been fitted to straight lines as Figure 2 shows, for each drying experiment. The critical moisture contents at the end of constant-rate period have been found to vary from 1.5 to 2.4 kg water/kg dry matter.

Figures 3 and 4 show plots in terms of $\ln \Gamma$ versus time. The equilibrium data were obtained from literature (Mazza and Le Maguer, 1978). Figures 3 and 4 show the influence of air velocity and air drying temperature, respectively, on the slope of the

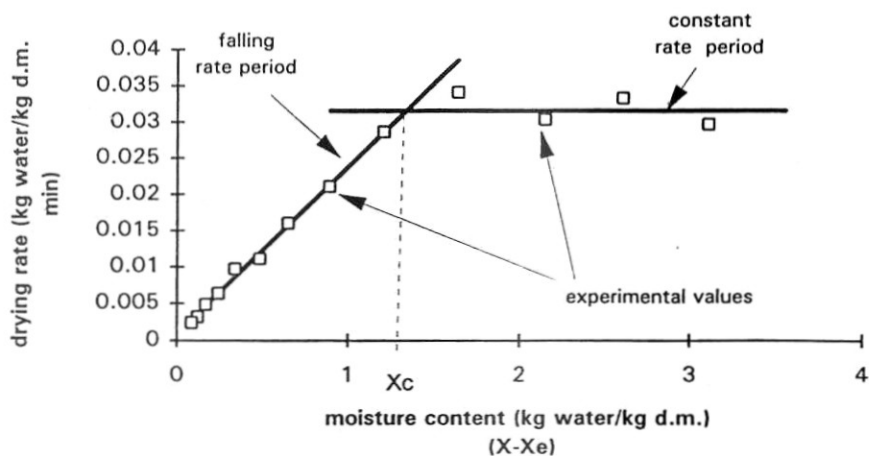


FIGURE 2. Drying rate (in kg water / kg dry matter \times min) versus moisture content ($X - X_e$), in kg water/kg dry matter, for a thin layer drying experiment of cut onion (variety E58-728).

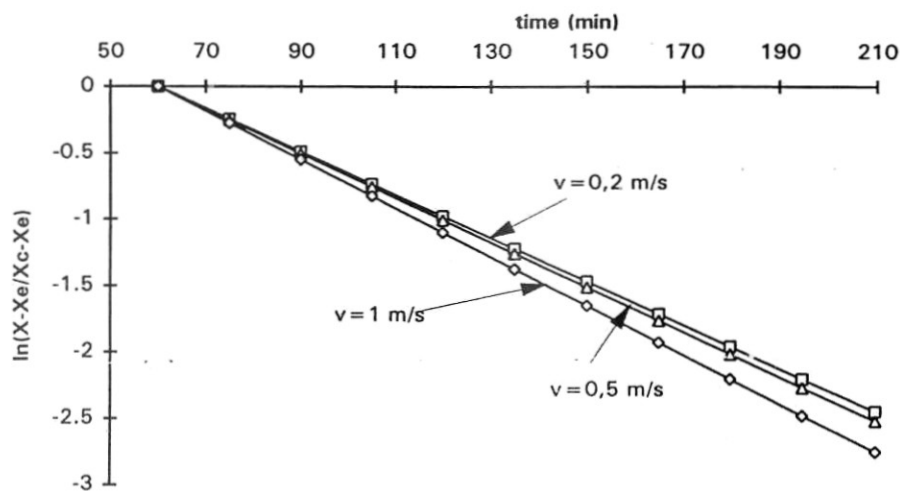


FIGURE 3. Dimensionless moisture versus time for different air velocities, in the falling-rate period of cut onion drying (variety S. White Globe).

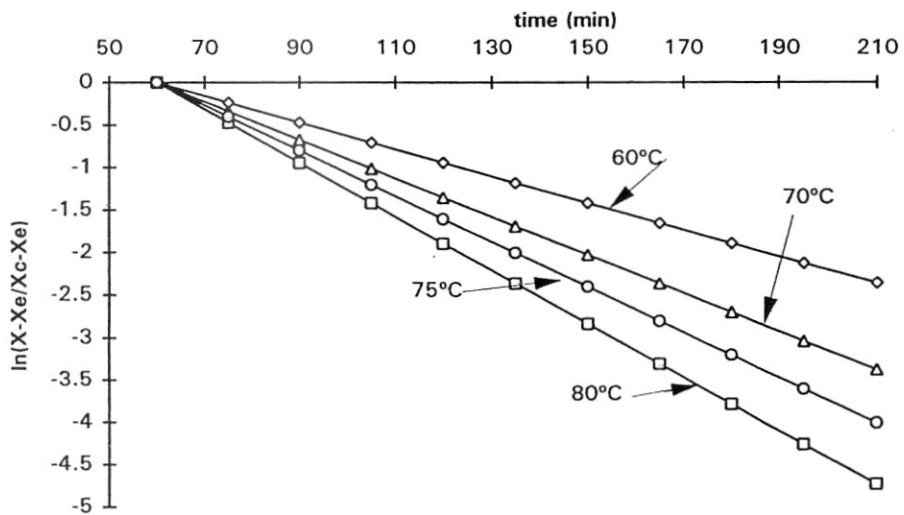


FIGURE 4. Dimensionless moisture versus time for different air temperatures, in the falling-rate period of cut onion drying (variety S White Globe).

linear relationship between \ln (dimensionless moisture) and the time. In this case, the slope of the straight lines has the value $(\pi^2/4.L^2).D_{eff}$; D_{eff} was obtained for each drying experiment. The diffusion activation energy found for sliced onion drying was 33.90 kJ/mol while D_o parameter (the effective diffusivity at high moisture contents, according to Okos et al., 1992) was $5.07 \times 10^{-5} \text{ m}^2/\text{s}$.

From Figures 3 and 4 is possible to see the influence of air velocity on the falling-rate is smaller than that of air temperature. Figure 5 shows effective diffusivity coefficient versus dry matter content for all the different onion varieties; it is correlated as:

$$\frac{D_{eff} - D_{min}}{D_o - D_{min}} = \exp(-kC_{dm}) \quad (3)$$

(Correlation coefficient = 0.9968)

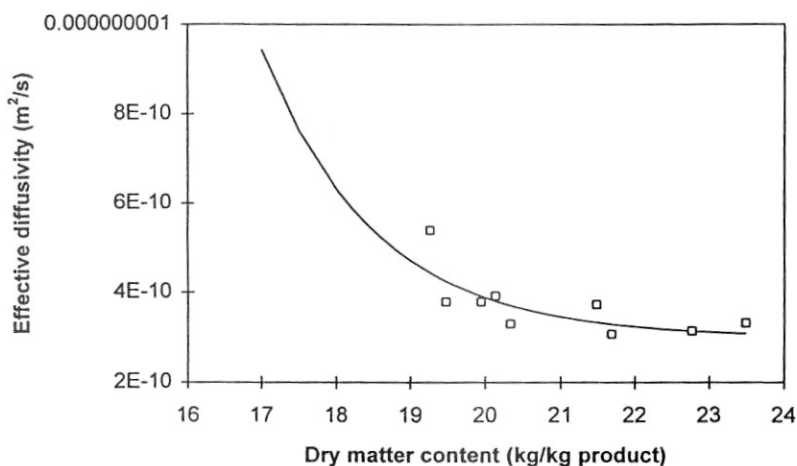


FIGURE 5. Effective diffusivity coefficient for transversely cut onion versus dry matter content of the raw onion from all the different varieties.

where C_{dm} is the dry matter content (kg/kg fresh product) of the raw onion, D_{min} is the minimum observed effective diffusivity ($3.0 \times 10^{-10} \text{ m}^2/\text{s}$), D_o is the parameter of the Eq.2 ($5.07 \times 10^{-5} \text{ m}^2/\text{s}$), and the constant k was found to be 0.6632.

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