DETERMINATION OF THE EFFECTIVE MOISTURE DIFFUSIVITY OF RED PEPPER IN A MICROWAVE CONVEYOR DRYER

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Abstract. In this study the drying process of red pepper (with thickness of 10mm, 15mm and 20mm) in a microwave conveyor belt dryer was investigated. The experiments were performed for 1.05kW, 1.5kW and 2.1kW microwave power and for 0.175m/min conveyor belt speed. The effective moisture diffusivity was determined by using Fick’s second law. The diffusion coefficient, activation energy and total energy consumption at the end of the drying process were calculated considering the experimental results.

Keywords: microwave conveyor dryer, red pepper, diffusion coefficient, activation energy.

1. INTRODUCTION

Red pepper (Solanaceae) which is commonly production in the world is a cultivar plant. Although it is possible in long-term storage cooling, frozen, through the process with chemicals, stored in gas composition controlled environment, ultraviolet and utilizing radioactive rays of fruit and vegetables, drying method is the widest application method in this applications. The purpose of drying; by reducing the water activity of the environment below a certain value, products is to make it resistant to chemical, microbiological and enzymatic degradation. A number of physical, chemical, mechanical, microbial and biochemical events comprise at the same time during the drying process that affect the quality properties of the final product [1]. Fresh and dried red peppers are produced largely both in the world and in the Turkey. Export of red pepper in Turkey is performed as red pepper flakes and powder [7].

Microwave heating has vast applications in the field of food processing over a period of several decades. The applications of microwave heating in food processing include drying, pasteurization, sterilization, thawing, tempering, ceramics, wood, baking of food materials and etc. [2, 3]. Microwaves are electromagnetic waves whose frequency varies within 300 MHz to 300 GHz. Microwave appliances operate generally at a frequency of 2.45 GHz, while industrial microwave systems operate at frequencies of 915 MHz and 2.45 GHz [4].

Many researchers have successfully dried vegetables with high heat-sensitive compositions, and fruits with high sugar contents. In all cases the drying time is reduced significantly, and in most cases the quality of the dried food products is improved [5].

2. MATERIALS AND METHODS

Fresh red peppers from a local market (Tekirdağ/Turkey) were selected. These were left in microwave conveyor belt dryer (500mmx400mmx3500mm) with maximum microwave power of 3kW. During the drying process, the conveyor speed was to regulate and could be set at the potentiometer of control unit. Periodically the samples were removed from each oven in order to measure their average weight with a Presica XB 620 M (Precisa Instruments AG, Dietikon, Switzerland).

2.1 Drying procedure

In order to determine the initial water content of the red peppers dried in an oven at 105°C for 24 h. The average initial moisture content of the material was measured 93%±1. The commercially dried red peppers were also supplied from the same location for comparison of quality parameters. Each drying experiment was independent, and the red peppers used for all were from the same supplier and had the same average initial moisture content. Prior to the drying experiment, the red peppers were washed with tap water, and cut into slices with thickness of 10 mm, 15 mm and 20 mm. Usual practice was applied in commercial red pepper production namely removal of fruit stems by hand, washing, cutting into slice and drying in a commercial continuous belt dryer at microwave power of 1.05kW, 1.5kW and 2.1kW, at conveyor belt speed of 0.175m/min. Drying tests were repeated three times for each test in order to minimize the uncertainties in the results.

Moisture ratio of samples during drying is generally calculated by the following equation [4]:

\[ MR = \frac{m - m_e}{m_o - m_e} \]  
\[ MR = \frac{m}{m_o} \]  

(1)

where \( m \) is moisture content (g water/g wet matter), MR is dimensionless moisture ratio, \( m_o \) is initial moisture contents (g water/g wet matter), \( m_e \) is equilibrium moisture content. The equilibrium moisture content was assumed to be zero for microwave drying.

2.2 Diffusion model

The method of slopes was used to estimate the effective moisture diffusivity of red pepper slices under different drying conditions. With decreasing moisture content, the drying characteristics may change during the drying process. This can be controlled by a diffusion mechanism, and in this study, red pepper slices were assumed to be infinite plates which are described by Ficks' second law and the effective moisture diffusivity \( D_{eff} \) within infinite plates can be estimated from the following Eq. (2). In case of symmetric boundary conditions and by neglecting the material shrinkage and with the assumption that water distribution in material to be homogeneous, the moisture ratio can be determined as follows [6]:

\[ MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \]  

(2)

Diffusivities are determined by plotting experimental drying data in terms logarithmic (MR) versus drying time \( t \) in the equation. The plot produces a straight line with the slope as given in Eq. (3):

\[ \text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \]  

(3)

In as much as temperature is not precisely measurable inside the microwave drier, the activation energy is found as modified from the revised Arrhenius equation. In this method it is assumed as related to effective moisture diffusion and the ratio of microwave output power to sample weight \( (m/P) \) instead of to air temperature as given [6] in Eq. (4):

\[ D_{eff} = D_a e^{-E_a/m \cdot f \cdot P} \]  

(4)

2.3 Determination of Energy Consumption

Energy consumption was measured with an electric counter (Köhler AEL.MF.03 brand, Turkey). Energy consumption values of microwave conveyor belt dryer were recorded using this device.

3. RESULTS AND DISCUSSION

3.1 Drying Curves

Figs. 2-4 show the change in moisture ratio of red pepper samples with time by microwave drying. It is clear that the moisture ratio decreases continuously with drying time. On the other hand, mass transfer within the sample was more rapid during higher microwave power heating because more heat was generated within the sample creating a large vapour pressure difference between the centre and the surface of the product due to characteristic microwave volumetric heating [6].

Drying process has been completed when final moisture content of the pepper with thickness of 10mm reached approximately 20% (w.b) for the
conveyor belt speed of 0.175 m/min. This moisture content value can be considered as final moisture content value for the pepper with thickness of 10 mm. Pepper darkens under this moisture content value. Similarly, final moisture content values are 16% (w.b) for thickness of 20 mm and 12% (w.b) for thickness of 20 mm.

Drying time decreases with the increase of the drying temperature in hot-air dryers. However, drying time may not decrease with increase of the microwave power in microwave conveyor dryers. As shown in Figs. 2-4 the drying time is shorter at 1500 W in comparison to the microwave power of 2100 W and the shortest drying time occurs during the microwave power of 1050 W. The drying system is an open system, so there are some energy losses. Microwave energy reaches products directly or by reflecting at different amounts. This case indicates the irregularities in drying time. Moreover the geometrical structure of the pepper and non-homogen water distribution in the product may cause irregularities in drying time.

Fig. 2. Drying curve of red pepper for thickness of 10 mm at 0.175 m/min conveyor belt speed.

Fig. 3. Drying curve of red pepper for thickness of 15 mm at 0.175 m/min conveyor belt speed.

Fig. 4. Drying curve of red pepper for thickness of 20 mm at 0.175 m/min conveyor belt speed.

3.2 Determination of effective diffusivity

The effective moisture diffusivity increased with decrease in moisture content. However, the moisture diffusivity further was higher at any level of moisture content at higher microwave power level, resulting into shorter drying time. This may indicate that as moisture content decreased, the permeability to vapour increased, provided the pore structure remained open. The temperature of the product rises rapidly in the initial stages of drying, due to more absorption of microwave heat, as the product has a high loss factor at higher moisture content.

This increases the water vapour pressure inside the pores and results in pressure induced opening of pores. In the first stage of drying, liquid diffusion of moisture could be the main mechanism of moisture transport. As drying progressed further, vapour diffusion could have been the dominant mode of moisture diffusion in the latter part of drying. Diffusivities are determined by plotting experimental drying data in terms logarithmic (MR) versus drying time t in the Fig. 5-7. The moisture diffusivities of red pepper slices increased from 7.76 x 10^{-7} to 4.95 x 10^{-6} m^2/s in accordance with the increase of microwave output power from 1.05 kW to 2.1 kW for different amount of samples. It can be seen that the values of $D_{eff}$ decreased with increasing microwave power. This might be explained by the increased heating energy which would increase the activity of the water molecules leading to higher moisture diffusivity when samples were dried at less microwave power. In a study conducted by Darvishi et al., 2014, effective diffusion coefficients of red peppers dried by microwave at different 7 microwave powers (180-540 W) were found to be varying between the values of
8.315×10^{-8}-2.363×10^{-7} m^2/s. They also calculated the activation energy as 14.19 W/g.

The activation energy was calculated by plotting ln(D_{eff}) versus the reciprocal of m/P. The plot was found to be a straight line in the range of microwave power studied, indicating Arrhenius dependence. The dependence of the effective diffusivity of red pepper samples can be represented in Table I.

<table>
<thead>
<tr>
<th>Microwave power</th>
<th>Equation</th>
<th>Activation energy</th>
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<tbody>
<tr>
<td>1050W</td>
<td>Ln(D_{eff})=-236.21(m/P)-12.614</td>
<td>236.21 W/g</td>
</tr>
<tr>
<td>1500W</td>
<td>Ln(D_{eff})=-296.17(m/P)-14.469</td>
<td>296.17 W/g</td>
</tr>
<tr>
<td>2100W</td>
<td>Ln(D_{eff})=-495.67(m/P)-14.982</td>
<td>495.64 W/g</td>
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Fig.5. Semi-logarithmic variation of moisture ratio of red pepper (10 mm) with time at 0.175 m/min conveyor belt speed.

Fig.6. Semi-logarithmic variation of moisture ratio of red pepper (15 mm) with time at 0.175 m/min conveyor belt speed.

Fig.7. Semi-logarithmic variation of moisture ratio of red pepper (20 mm) with time at 0.175 m/min conveyor belt speed.

3.3. Results on Energy Consumption

The energy consumption during microwave drying was read and recorded with certain period using a counter. Energy consumption values were measured as 105.2, 106.9 and 109.1 kWh for 1050W power levels and 0.175m/min belt speed for 10 mm, 15mm and 20mm layer thickness, as as 113.4, 112.7 and 112.1 kWh for 1500W power levels and 0.175m/min belt speed for 10 mm, 15mm and 20mm layer thickness and as 115.4, 115.1 and 114.8 kWh for 2100W power levels and 0.175m/min belt speed for 20mm layer thickness. Drying time decreases with the increase in microwave power. However, microwave power of 1500W takes the longest time. This situation originates from non-homogen water distribution in the product. Energy consumption increases with increase in microwave power.

4. Conclusions

The effective moisture diffusivity increased with decrease in moisture content of red pepper samples. The average effective diffusivity varied from 7.76×10^{-7} to 4.95.10^{-6} m^2/s in the microwave power range of 1050–2100W. The activation energy was found to be 236.21, 296.17 and 495.64W/g. Specific energy consumption and drying efficiency in microwave drying of pepper slices ranged between 105.2 and 115.4kWh. We concluded that 1050W is the optimum microwave power level in the microwave drying of pepper slice (10mm) with respect to energy consumption.
REFERENCES