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Shrinkage and porosity effects on heat and mass transfer during potato drying

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ABSTRACT

Fruits and vegetables are porous in nature and undergo pronounced shrinkage during convective drying process. Therefore, shrinkage and porosity should be taken into consideration while predicting heat and mass transfer. This work was conducted to study shrinkage and porosity changes along with simultaneous heat and mass transport during the process. Potato slices were subjected to drying for 7 h at 62 °C. It was observed that shrinkage varies linearly with respect to moisture content and reduction in radial dimension of potato slices was around 35%. Porosity undergoes rapid increase after attaining certain moisture content in final stages of drying. The work was extended to study the influence of shrinkage and porosity on heat and mass transfer. Simulated results were validated with experimental values. This model can be employed to predict temperature, moisture, density profiles and to study shrinkage and porosity of various fruits and vegetables.

1. Introduction

Fruits and vegetables are porous, non-homogenous and high moisture containing food stuffs, and therefore extremely perishable in nature due to microbial spoilage. Reduction of water from the fruits and vegetables using different drying techniques is widely employed to prolong the shelf life of these food commodities. Among various drying techniques available, convective drying is most widely employed method due to its simplicity and cost effectiveness. Heat transfer occurs inside the sample by conduction and mass transfer takes place by diffusion in accordance with temperature and moisture concentration gradient respectively (Srikiatden and Roberts, 2008). But, during drying fruits and vegetables undergo prominent porosity changes as well as 'shrinkage'. Shrinkage can be understood as significant structural deformation in shape and size of sample occurring along with simultaneous heat and mass transfer (Mayor and Sereno, 2004). During drying of vegetables, when moisture is removed from the surface tissues, the wall of water filled pores experiences a pressure which drags the entire matrix towards the center .This contraction stress results in prominent structural changes in shape and size of sample (Yang et al., 2001). In drastic drying conditions, food samples are also found to develop cracks on its surface which is due to disturbance in mechanical stress and strain equilibrium inside the matrix structure because of non-uniform shrinkage. The entire process is governed by various physical and chemical changes taking place inside the food. Additionally, sample porosity continuously changes with change in matrix structure during the entire process. Porosity is a relative term used to express ratio of void volume within sample to the volume occupied by material in the sample. As the drying proceeds, intracellular spaces (pores), previously occupied by water are replaced either by air or is compressed as result of shrinkage (Marquez and Mechalis, 2011). The porosity of sample increases as the pores containing water is replaced with air. Porosity is important in determining textural and sensory quality of product like crispiness, crunchiness, etc. The force applied and vibration produced due to rupture of cell wall filled with air on cutting and chewing decides the sensory parameters of product (Rahman, 2001). In turn, the drying behavior of sample is strongly influenced by this combined effect of shrinkage and porosity changes, which takes place during drying. Heat and mass transfer rate changes with reduction in area which is dictated by shrinkage pattern (May and Peree, 2002) and it increases with increase in average pore size (Karathanos et al., 1996). These events ultimately affect the structural, textural, and sensory quality of food, which determines its acceptance in market (Tasami and Katsioti, 2000).

As porosity and shrinkage are critical factors, influencing transport mechanism as well as product quality parameters, it becomes important to include porosity and shrinkage while predicting drying process and for better optimization of process. Since, these structural changes and transport processes occurs simultaneously

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Nomenclature

A	area of sample (m^2)
C_P	specific heat (J/kg K)
C	moisture concentration (mol/m^3)
D_{eff}	diffusion coefficient of potato(m^2/s)
D_f	free diffusion coefficient
E	relative percentage error
h	heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
M	moisture content
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
R	radius of sample (cm)
r	radial dimension at time t
S_R	shrinkage
T	temperature (K)
t	time (s)
V	velocity of shrinkage (m/s)
Y	change in dimension (m)
E (%)	relative error percent

Greek symbols

ρ	density (kg/m^3)
τ	tortuosity factor
ε	porosity
θ	volume fraction

Superscripts and subscripts

a	air
b	bulk
b_0	bulk dry solid
db	dry basis
i	Inside
int	initial
eq	equivalence
L	fluid
o	outside
s	dry solid
wb	wet basis
w	water
p	particle

and continuously throughout the process, it becomes tedious to account this entire phenomenon together in a single model. Many of the researchers have developed mathematical models (Pandit and Prasad, 2003; Srikiatden and Roberts, 2006, 2008) and theoretical model (Aversa et al., 2007; Curcio et al., 2008) to predict heat and mass transfer in various food products for different industrial set ups. But these models have been developed without considering shrinkage i.e. sample having constant dimensions and neglecting porosity changes during the drying process. Model predicting shrinkage and simultaneous heat and mass transfer in potato has been reported (Wang and Brennan, 1995a; Yang et al., 2001) but even these models consider food structure as compact and continuous, having negligible porosity. Thus, aim of this present work is to predict and validate, shrinkage and porosity changes occurring along with simultaneous heat and mass transfer during convective drying of potato slices. Further, the work was extended to study effects of shrinkage and porosity on heat and mass transfer.

2. Materials and methods

2.1. Sample preparation

Fresh potato (*Solanum tuberosum*) was purchased from local supermarket, washed using tap water, peeled and uniform sample sizes of 4.5 cm in diameter and 0.7 cm thickness were obtained measured using vernier caliper. The samples were subjected to blanching at 75 °C for 15 min (Srikiatden and Roberts, 2008) to reduce enzymatic reactions leading to various undesirable reactions such as color, off-flavor and textural changes in the product (Gornicki and Kaleta, 2007).

2.2. Moisture and temperature profile analysis

Moisture content of potato slices were determined by employing gravimetric method, assuming that the loss of weight in sample is attributed only to loss of moisture during drying. Initial weight of sample (10.8 g) was recorded and samples are subjected to convective drying at 62 °C for 7 h with airflow rate of 0.25 (m/s). Change in weight of sample has been recorded every 15 min to study the moisture profiles. Bone dry weight of sample is estimated (triplicates) by oven drying method i.e. drying sample for 8–10 h at 105–110 °C (McMinn and Magee, 2003). Initial and final moisture content was calculated and found to be 82% (wb) and 21% (wb) respectively.

To study temperature profile within the sample and inside hot air oven, calibrated T-type thermocouples were inserted at the geometric center of potato slices. All the thermocouples were connected to the data logger (VR-18, Brainchild Electronics Co. Ltd. Taiwan) and temperature is recorded at regular intervals of 30 s at 62 °C. Pictorial representation of this experimental setup is shown in Fig. 1.

2.3. Shrinkage analysis

The shrinkage was measured as ratio of diameter at respective time, to the original diameter of sample. Images of the samples

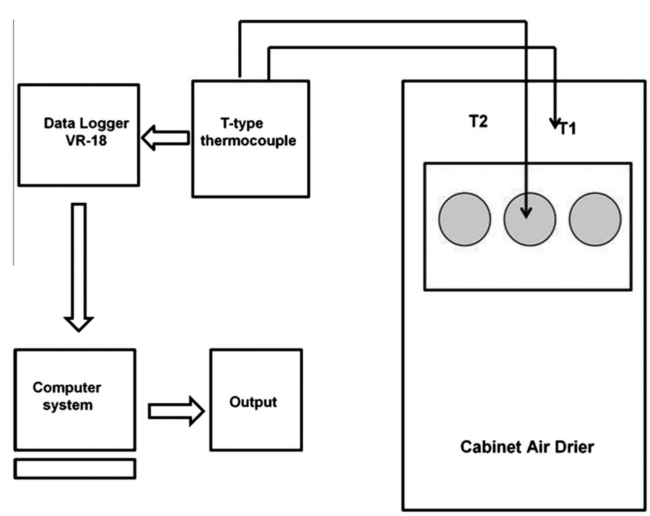

Fig. 1. Schematic arrangement of the experimental setup.