Applied Thermal Engineering 62 (2014) 455–460

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Influence of process control strategies on drying kinetics, colour and shrinkage of air dried apples

Barbara Sturm [a,b,*], Anna-Maria Nunez Vega [b], Werner C. Hofacker [b,c]

[a] Department of Agricultural Engineering, Kassel University, Nordbahnhofstrasse 1a, Witzenhausen D-37213, Germany
[b] Department of Process and Environmental Engineering, Thermal Process Engineering, University of Applied Sciences Konstanz, Braunegger Straße 55, Konstanz D-78462, Germany
[c] Institute for Applied Thermo- and Fluiddynamics IaTF, University of Applied Sciences Konstanz, Braunegger Straße 55, Konstanz D-78462, Germany

HIGHLIGHTS

- Development of quality attributes significantly depends on control strategies.
- Online measurements show that information can be used for process control optimisation.
- Product temperature controlled drying is gentler at comparable drying times.

ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 30 September 2013
Available online 16 October 2013

Keywords:
Apple
Convective drying
Drying kinetics
Process control
Colour
Shrinkage
Product temperature

ABSTRACT

The influence of two different control strategies, constant air temperature and constant product temperature, on product quality and drying behaviour of apples was investigated. The interactions of the drying parameters air temperature (35–100 °C), product temperature (35–85 °C), dew point temperature (5–30 °C) and air velocity (2.0–4.8 m/s) with drying time, colour changes and shrinkage were measured continuously and determined for both strategies. Based on these results the two strategies were compared with regards to their effect on drying performance.

The results show that the drying strategy has a significant influence not only on the development and duration of the drying process but also on the development of colour changes and shrinkage. Controlling product temperature led to shorter drying times and generally lower colour changes. Furthermore, it was shown that the product temperature develops characteristically; two stages and a clearly visible transition period can be detected. This potentially can be used to control the process and, therefore, improve its performance regarding duration and quality aspects.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Convection drying is one of the oldest and most wide spread means of preserving food. It was identified a long time ago that, as most food products are heat sensitive, the crucial factor in the convection drying of food and other sensitive agricultural products are the product temperature and, in particular, preventing that temperature from exceeding critical levels. Excessive temperatures lead to structural, organoleptic (smell, taste, visual appearance, chewiness etc.) and nutritional changes [1]. The extent of changes of the most important quality characteristics like colour (pigments, enzymatic and non-enzymatic browning) and nutritional value (anti-oxidants, vitamins) usually increases with increasing temperature. The dependency of reaction constants on temperature allows for the assumption that drying at lower temperatures leads to a lower loss of valuable compounds [2]. However, traditionally, the drying process is controlled by keeping the air temperature constant on a predefined level. Often product temperature is unknown or if it is measured it is not included in the process control system [3]. The changes of product characteristics during the drying process are related to reactions of zero-order or 1st order [4] and usually product temperature is assumed to be constant. However, several studies on medicinal herbs, fruits and vegetables [5–7] have shown that for products with high initial product moisture content, product temperature changes almost throughout the process and only comes close to air temperature at the end of the process.

* Corresponding author. Newcastle Institute for Research on Sustainability, Newcastle University, Newcastle upon Tyne NE1 7RU, UK. Tel.: +44 191 246 4951.
E-mail addresses: barbarasturm@daad-alumni.de, barbara.sturm@newcastle.ac.uk (B. Sturm).

1359-4311/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2013.09.056

Nomenclature

A	air
ΔE	total colour difference
P	product
R^2	coefficient of determination
S	shrinkage
t	time (min)
v	velocity (m/s)
$\bar{x}$	arithmetic mean
x	independent variable
X	moisture content (g_W/g_{DM})
y	response variables

Greek letters

β	approximated coefficient
ε	experimental variance
φ	relative humidity (%)
σ	standard deviation
ϑ	temperature (°C)

Subscripts

A	air
dp	dew point
Dr	drying
DM	dry matter
P	product
W	water

Several authors have shown for different sensitive biological products [8,9] that they are not excessively damaged when exposed to high air temperatures during the first period of drying. This can be explained by the initially very high moisture content of the product that leads to a great difference between dry and wet bulb temperature, therefore no thermal damage is risked in this phase.

A multitude of studies have investigated the influence of drying conditions in convection drying on drying kinetics and quality aspects of apples [9–16]. The general consent is that increase of air temperature has the most significant influence on drying kinetics, in addition to colour change, whilst high air velocity is regarded as reducing shrinkage [17].

In recent years, the importance of dynamic process control has gained increased recognition in production of dried food stuffs. Research on the influence of periodically changing drying conditions showed that reducing temperature step wise from an initially high temperature results in a reduction of colour changes in guava [18]. Product quality of dried potatoes can be improved by cyclically changing drying conditions [19]. Cho and Chua [20] concluded that intelligent online-control of drying necessitates step wise change of air temperature and observation of product temperature. However, only a very limited number of studies have actively controlled the product temperature. Isothermal drying has been used for control of combined drying processes and for the measurement of effective diffusivity and shrinking of hygroscopic materials [13,21]. Nonetheless, only a few studies [22] have actually obtained and verified isothermal conditions, uniform temperature is usually assumed. According to Srikiatden and Roberts [23] isothermal conditions may be possible for convective hot air drying of a porous material having a very small characteristic dimension. Lengyel [24] showed that for the system in question, in bodies with less than 10 mm thickness, the core warms very quickly and therefore the body temperature is quasi uniform.

Colour and shrinkage are two of the most important aspects in determination of product quality. They are both directly related to consumers' appreciation of a product as they tend to associate product colour and other visual properties with its taste, hygienic security, shelf life, nutritional value and personal satisfaction [25]. Furthermore, colour is directly linked to aroma and taste of the product [26] while shrinkage tends to be linearly related to moisture content [27]. The degree of shrinkage depends directly on the temperature, humidity and velocity levels applied.

This paper is concerned with the determination of the influence of drying strategy and conditions on the quality of dried apples and performance of the process represented by the duration, temperature and product quality developments. Colour and two-dimensional shrinkage have been used as indicators of product quality as they comprehensively represent stresses during drying.

2. Materials and methods

2.1. Raw material

Apples of the Jonagold variety were used as experimental material. Fruits were obtained from a local farmer (Lake Constance, Germany) and stored in the fridge at 4 °C. Before drying, raw material was cut into slices of 3.9 mm ± 0.2 mm thickness with an outer diameter of 72 mm and an inner diameter of 20 mm. Average weight per slice was 13 g ± 0.2 g.

2.2. Convection drying

Drying tests were carried out using a high precisions laboratory dryer developed in the department of Thermal Process Engineering, University of Applied Sciences Konstanz, Konstanz (Germany). The experimental system essentially comprises of 5 units: (i) an air flow control unit, (ii) an air conditioning unit, with a water bath including heating and chilling units and a packed bed, (iii) a heating control unit with heating elements, (iv) a drying compartment that allows for either over or through flow air stream for convective drying of product (v) a non-invasive online measurement system, including a CCD camera and a pyrometer. A detailed description of the dryer was given by Sturm and Sturm et al. [7,28].

For the air temperature controlled tests, the dryer was pre heated for 20 min to reach the defined set temperatures. The apple slices were then distributed as described by Sturm [28]. The total weight of the samples was approximately 90 g. In the case of surface temperature control the dryer was turned on at the start of the experiment. Air temperature controlled drying was conducted at 35, 45, 60, 75 and 85 °C. Product temperature controlled drying was conducted at 35, 40, 47.5, 55 and 60 °C. During experiments where product temperature was controlled, maximum air temperature was limited to 100 °C. This was due to the fact that the industrial dryers in question are not operating at any temperatures higher than 100 °C. Dew point temperature was set to 5.0, 10.0, 17.5, 25 and 30 °C and air velocity to 2.0, 2.6, 3.4, 4.2 and 4.8 m/s for both strategies investigated. The samples were dried until they reached a moisture content of approximately 0.13 g_W/g_{DM}. This moisture content was chosen because it is typically used in production of dried apple products ($a_W = 0.5$ [29] in desorption and 0.52 to 0.55 [30] in absorption).

During drying, the weight, air temperature and product temperature were measured continuously. Colour and two dimensional shape (visible cross section) of samples were measured every five minutes using the integrated CCD camera (The Imagingsource DFK 31BU03.H). The details of the optical systems as well as the calibration were described in Sturm et al. [7]. For the representation of

Download English Version:

https://daneshyari.com/en/article/646358

Download Persian Version:

https://daneshyari.com/article/646358

Daneshyari.com