Journal of the Saudi Society of Agricultural Sciences (2014) 13, 81–91

King Saud University

Journal of the Saudi Society of Agricultural Sciences

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FULL LENGTH ARTICLE

Energy and exergy investigation of microwave assisted thin-layer drying of pomegranate arils using artificial neural networks and response surface methodology

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Received 14 October 2012; accepted 30 January 2013
Available online 9 February 2013

KEYWORDS
Pomegranate arils;
Energy;
Exergy;
Artificial neural network;
Response surface methodology;
Modeling

Abstract Energy and exergy analyses of thin-layer drying of sour pomegranate arils with microwave treatment were conducted in this research. Three levels of air temperature (50, 60 and 70 °C) and air velocity (0.5, 1 and 1.5 m/s) were tested for evaluation of dryer parameters. Energy utilization and energy utilization ratio increased with time, while exergy efficiency decreased with time. Application of microwave pretreatment to assist convective drying resulted in decreased energy utilization and drying time. Minimum exergy loss and exergy efficiency were also obtained using microwave pretreatment. Artificial neural networks (ANN) performed desirably in modeling energy and exergy criteria regarding input factors. Results showed that the training algorithm of back-propagation was suitable for predicting the drying parameters. It was also found that response surface methodology (RSM) predicted desirably the output parameters. Coefficient of determination (R^2) values for regression of drying energy and exergy criteria based on input factors were obtained to be highly acceptable for both ANN and RSM models.

1. Introduction

Drying is known as the best method to preserve fruits and vegetables. Water removal during drying prevents microorganism evolution and harmful chemical reactions leading to longer storage time (Barbosa-Canovas and Vega-Mercado, 1996). Mathematical models of thin-layer drying provide little information on the dryer energy analysis. As a consequence, they would not be useful for design and optimization purposes. Thermodynamic analysis, particularly exergy analysis, plays

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

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http://dx.doi.org/10.1016/j.jssas.2013.01.005

Nomenclature

EU	energy utilization (kJ/s)	T_∞	temperature of medium (°C)
m_{ai}	inlet air flow (kg/s)	EUR	energy utilization ratio
h_{ai}	inlet air enthalpy (kJ)	h_∞	enthalpy of the medium air (kJ/kg)
m_{ao}	outlet air flow (kg/s)	Ex	exergy of air or inlet/outlet product (kJ/s)
h_{ao}	outlet air enthalpy (kJ/kg)	m	mass flow of inlet/outlet air (kg/s)
p_a	air density (kg/m^3)	C	specific heat of inlet/outlet air (kJ/kg°C)
V_a	inlet air velocity (m/s)	E_l	exergy loss
A_{dc}	dryer area section (m^2)	Ex_{eff}	exergy efficiency
o	predicted output value	p	number of patterns
t	target value		
T_a	inlet or outlet air temperature (°C)		

an important role for system design, analysis and thermal system optimization. Exergy analysis evaluates the accessible energy within several points and presents advantageous information for a favorable design methodology and part selection in a dryer. Exergy is defined as the maximum work produced by heat and vapor at the equilibrium state (Dincer, 2000, 2002). Energy and exergy analyses reported on drying fruits and vegetables by Akpinar et al. (2004), Midilli and Kucuk (2003b), Ceylan et al. (2007) and (Corzo et al., 2008).

Modeling and optimization to increase the efficiency of the process is one of the most important stages in a thermal process. The relationship between interfering factors and final outputs is of great value for researchers and technicians. However, many numerical methods have major drawbacks in finding constants and solving the complexities of non-linear behaviors (Collins, 2003). Due to these disadvantages, researchers have looked for alternative methods. One of the most popular approaches used in the last two decades is response surface methodology (RSM). RSM is a combination of mathematical and statistical techniques that is useful for analyzing, developing, improving, and optimizing processes in which a response of interest is influenced by several variables and the objective is to optimize this response without the need for a predetermined relationship between the objective function and the variables (Myers and Montgomery, 2002; Draper and Lin, 1990; Draper and John, 1988). RSM is mainly used for optimization of media component, reaction parameter or for scaling up the condition. Prediction of model equation, which describes the effects of independent variables, is one of the steps of RSM optimization procedures (Anjum et al., 1997; Myers and Montgomery, 2002). Although RSM has many advantages, it would be unwarranted to say that it is applicable to all optimization and modeling studies.

A well trained network learns from the pre-seen experimental dataset (training data) and generalizes this learning beyond to the unseen data which is called ‘prediction’ (Haykin, 1994). Furthermore, artificial neural networks (ANNs) are able to model non-linear behaviors and complex processes. This is highly important considering the drying applications in which the nature is seriously non-linear and simple modeling methods fail (Haaland,1989). Although ANN methods are frequently reported on drying fruits and vegetables (Momenzadeh et al., 2011; Hernández, 2009; Aghbashlo et al., 2008; Movagharnejad and Nikzad, 2007), few researches are dedicated to exergy analysis and energy considerations.

The objective of this paper is to develop ANN and RSM models for mapping input factors including temperature, air velocity, microwave pretreatment and time with the output energy performance of the thin-layer dryer for pomegranate arils. An optimized combination of factors in order to yield maximum efficiency out of dryer will also be achieved using RSM.

2. Materials and methods

2.1. Energy analysis

Fresh samples of sour pomegranates collected from Jooybar in Mazandaran province of Iran were stored at 5 °C in a refrigerator. Moisture content of pomegranate arils was determined gravimetrically to be 331% (dry basis) (Doymaz 2005). The experiments were carried out at three temperature levels of 50, 60, and 70 °C and three levels of hot air velocity, 0.5, 1, and 1.5 m/s. Three treatments including control treatment (convective drying only), microwave pretreatment (100 W power) for 20 min, and microwave pretreatment (200 W power) for 10 min were implemented. Air temperature and velocity were measured using an electric thermometer (Lutron, TM-925, Taiwan) and anemometer (Lutron-YK, 80 AM, Taiwan), respectively. Air pressure was measured by a pressure gage (PVR 0606A81, Italy). While moisture meter (Testo 650, 05366501, German) was applied to measure the moisture content of samples during the experiment. Microwave pretreatment of pomegranate arils was achieved using a microwave apparatus (SAMSUNG, 75DK300036V, model: M945, Korea). Experimental set up is illustrated in Fig 1.

2.2. Energy analysis

Heater energy utilization can be calculated using the conservation energy law of thermodynamics (Corzo et al., 2008):

$$\mathrm{EU} = m_{da}(h_{dai} - h_{dao}) \tag{1}$$

in which EU is energy utilization (kJ/s); m_{da}, mass flow dry air (kg/s); h_{dai}, inlet dry air enthalpy and h_{dao}, outlet dry air enthalpy (kJ/kg).