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Modeling of a convective-infrared kiwifruit drying process

M. Bahadır Özdemir [a], Mustafa Aktaş [a], Seyfi Şevik [b,*], Ataollah Khanlari [c]

[a] Gazi University, Technology Faculty, Energy Systems Engineering, Ankara, Turkey
[b] Hitit University, Vocational School of Technical Sciences, Electrical and Energy, Çorum, Turkey
[c] Gazi University, Natural and Applied Science Institute, Ankara, Turkey

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ABSTRACT

This paper aims to evaluate the experimental performance of a convective-infrared system with heat recovery (CIRHR) at different drying temperatures (40, 45, 50 and 55 °C) and 0.5 m/s air velocity and also to discuss and predict the performance of system on energy consumption and drying kinetics of sliced kiwifruit using artificial neural networks (ANNs). The energy efficiency values were obtained between 2.85% and 32.17%. The ANN model was used to predict the energy consumption of the system and moisture content of the kiwifruit. The back-propagation learning algorithm with Levenberg–Marquardt (LM) and Fermi transfer function were used in the network. The coefficient of determination (R^2), the root means square error (RMSE) and the mean absolute percentage error (MAPE) were calculated as 0.99, 0.001 and 0.34, respectively. It can be concluded that predicted values are in good agreement with experimental results.

Introduction

Drying is the best method for preserving foods. However, drying needs high energy input, but World's energy resources are limited. Thus, to balance energy demands, the development of energy systems with high efficiencies and minimal costs are important [1]. The dryers need the various types of energy sources. Each drying method has some limitations [2] due to the influence of some factors (product, drying method and conditions, structure of the dryer, etc.) affecting drying efficiency. In literature, many studies has been carried out with dryers in combined forms such as solar-heat recovery assisted infrared and infrared–heat pump and non-combined dryers such as infrared and microwave. These studies focused on reducing the drying costs [3–7].

In industry, infrared energy is preferred because heat and mass transfer rates are high. Infrared technology is used in many different fields (drying [4]; oxygenic photosynthesis [8]; H_2 production [9]; measurement equipment [10]). Especially, it is considered often in the drying applications. Although, different drying techniques [2,3,5–7] are applied to products, infrared drying is accepted as an effective method [4,11,12]. Gulcimen et al. [2], proposed a new model for sweet basil drying by using obtained drying parameters. Aktaş et al. [3], analyzed heat and mass transfer characteristics of the dryer

* Corresponding author.
E-mail addresses: mbozdemir@gazi.edu.tr (M.B. Özdemir), mustafaaktas@gazi.edu.tr (M. Aktaş), seyfisvk@hotmail.com (S. Şevik), ata_khanlari@yahoo.com (A. Khanlari).
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Nomenclature

A	area, m^2
ANN	artificial neural network
$c_{p,a}$	specific heat capacity of air, kJ/kg K
DR	drying rate, g water/(g dry matter minute)
h_{fg}	latent heat, kJ/kg
R_a	ideal gas constant, kJ/kg K
X_{db}	moisture content, g water/g dry matter
M_i	initial wet weight, g
M_d	final dry weight, g
X_t	moisture content at time "t", g water/g dry matter
MC_{t+dt}	moisture content at time "t + dt", g water/g dry matter
Me	equilibrium moisture content, g water/g dry matter
X_o	initial moisture content, g water/g dry matter
$\dot{m}$	flow rate of air, kg/s
m_w	vaporized water weight, kg
MAPE	mean absolute percentage error
MR	moisture ratio, %
P	power, W
R^2	coefficient of determination
RMSE	root means square error
t	time, minute
$\dot{V}$	volumetric flow rate of air, m^3/s
V_{min}	the minimum value in all the values for related variable
V_{max}	the maximum value in all the values for related variable
σ	Stefan–Boltzmann constant, 56.7×10^{-12} kW/m^2 K^4
ε	emission coefficient
W_R	the total uncertainty, %
w_1, w_2, w_n	the uncertainties in the independent variables

Subscripts

a	air
aa	ambient air
e	experiment
Ex	exhaust
f	fan
is	initial surface
us	upside skin
oth	others
p	vapor pressure of water, kPa
pr	predicted
prd	product
R	the function uncertainty
x	independent variables
w	water
0	reference

and three dimensional (3-D) computational fluid dynamic (CFD) simulation. They reported that solar air collector and heat recovery unit have a key role in their system.

Kiwifruit (*Actinidia deliciosa*) has high vitamin C content. It is a very important fruit species in terms of healthy nutrition due to its low calorie level. Kiwifruit production in Turkey started in 1994. Today, Turkey is among the first ten countries in the kiwifruit production. Generally, the kiwifruit is consumed as fresh. In Japan, approximately 16% of the kiwifruit is discarded as "food loss" [13]. Also, it can be stored between 2 and 6 months. Therefore, the shelf life of the kiwifruit can be extended with drying. Some researchers studied on kiwifruit drying; in a hot air dryer [5,14,15], a microwave dryer [6,13,16] and a solar assisted heat pump dryer [17]. Orikasa et al. [5], and Maskan [6] applied a nonlinear least squares method and zero- and first-order kinetic models to describe colour change in kiwi fruit drying, respectively. Orikasa et al. [13], said that vacuum drying was a more suitable method than hot air drying based on L-ascorbic acid in kiwifruit. Simal et al. [14], proposed three models and correlated with the drying air temperatures. Some researches [15–17] investigated the experimental and numerical analysis of heat and mass transfer using generated code by the authors, energetic and exergetic performance analysis and drying kinetics of kiwi fruit, respectively. The higher drying temperatures and longer drying times cause color quality negatively. This can be prevented by using infrared method at low temperatures.

ANN modeling is widely used in many fields. Especially, it is used in energy and drying systems in recent years due to the fact that it uses experimental data and has been used by many researchers [18–22]. Many researchers studied ANN models for solving complex and nonlinear problems on various energy system [19]; ground coupled heat pumps [20]; closed-loop heat pump dryer [21]. Also, ANN modeling has been applied based on product (bay leaves [21]; apple [22]). ANN modeling has been proposed by the researchers obtaining successful models. The researchers stated that significant relationship could be described between the experimental data, the data number of training set, validation and test set to increase the learning capability of the network.

Although there are a few reports on the application of different drying techniques, there is no comprehensive report on performance evaluation and modeling of convective-infrared dryer with heat recovery (CIRHR) by drying kiwifruit. The present study focused on the actual operation and modeling to evaluate energy demand and the drying kinetics of kiwifruit. In this study, it is taken into consideration because the browning is one of important quality parameters. It depends on drying conditions. This type of dryer was preferred due to the fact that infrared energy is an effective method for drying time and heat recovery unit is also effective for recovering energy. Furthermore, although many researchers have modeled the drying process using ANNs, authors have considered the effect of energy consumption and moisture content to estimate the actual experimental data.

Material and method

Experimental setup

Experiments were carried out in a CIRHR system. The drying system can be seen in Fig. 1. The drying system consist of near