Energy xxx (2016) 1–12

Contents lists available at ScienceDirect

Energy

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

# Application of artificial neural network method to exergy and energy analyses of fluidized bed dryer for potato cubes

Mohsen Azadbakht*, Hajar Aghili, Armin Ziaratban, Mohammad Vahedi Torshizi

*Department of Bio-system Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran*

## ARTICLE INFO

*Article history:*
Received 14 March 2016
Received in revised form
1 December 2016
Accepted 2 December 2016
Available online xxx

*Keywords:*
Energy utilization
Exergy loss
Potatoes
Fluidized bed dryer
Artificial neural network

## ABSTRACT

Drying the samples was performed in the inlet temperatures of 45, 50, and 55 °C, air velocity of 3.2, 6.8, and 9.1 m $s^{-1}$, and bed depth of 1.5, 2.2, and 3 cm. The effects of these parameters were evaluated on energy utilization, energy efficiency and utilization ratio and exergy loss and efficiency. Furthermore, artificial neural network was employed in order to predict the energy and exergy parameters, and simulation of thermodynamic drying process was carried out, using the ANN created. A network was constructed from learning algorithms and transfer functions that could predict, with good accuracy, the exergy and energy parameters related to the drying process. The results revealed that energy utilization, efficiency, and utilization ratio increased by increasing the air velocity and depth of the bed; however, energy utilization and efficiency were augmented by increasing the temperature; additionally, energy utilization ratio decreased along with the rise in temperature. Also was found that exergy loss and efficiency improved by increasing the air velocity, temperature, and depth of the bed. Finally, the results of the statistical analyses indicated that neural networks can be utilized in intelligent drying process which has a large share of energy utilization in the food industry.

## 1. Introduction

Potato (*Solanum tuberosum* L.) is categorized among the products with broad area under cultivation in the world and is ranked fifth in terms of production. This glandular product is not only rich in hydrocarbons, it is also an important source of minerals and vitamins. In developed countries, approximately 500 million people consume potatoes [1]. It should be noted that potato is one of the most important agricultural crops and can have many losses due to unfavorable storage in warehouses and inappropriate processing; thus, drying this product leads to increasing its shelf life [2]. In addition to drying potato which is the best way to minimize agricultural waste, packaging and shipping dried potato will be easier and cheaper due to the lower weight and volume of dry products [3].

In general, dried potato products are divided into two categories: cooked and raw. The first group consists of the dried mashed potatoes such as pellets, flake, or agglomerates. The second group includes dried potato slices, dried potato cubes, and dried grated potatoes. There is a high risk of corruption in potatoes due to their high amount of water. Drying has been one of the oldest methods for preserving various agricultural and food products. One of the main purposes of drying agricultural products is transporting the water in the solid texture to the product surface area up to a certain level, so that microbial damages and routine chemical reactions would basically reach the lowest possible amount [2]. Moreover, owing to the latent heat of evaporation of water and relatively low efficiency of drying, the drying process requires a high energy [4]. Given that approximately 10% of the total energy utilization in food industry is allocated to the dried material [5], energy analysis is beneficial in the quantitative assessment of energy intake, energy production, energy delivery systems, diagnostic mode, and loss of energy. Information obtained from the analysis of energy can be applied to determine the energy conservation practices. The first law of thermodynamics, which is known as the principle of conservation of energy, is generally exercised to analyze the performance of engineering systems [6].

Exergy also evaluates the energy available in various parts of the system. Exergy analysis method provides valuable information on proper selection of design components and techniques employed in system design. Such information has a much more effective role in determining the design, operation cost, energy storage and fuel

---

* Corresponding author.
*E-mail address:* azadbakht@gau.ac.ir (M. Azadbakht).

http://dx.doi.org/10.1016/j.energy.2016.12.006
0360-5442/

Please cite this article in press as: Azadbakht M, et al., Application of artificial neural network method to exergy and energy analyses of fluidized bed dryer for potato cubes, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.12.006

switching capability [7]. Exergy analysis is a significant strategy used in the design of energy systems and is the best method to design the process. The above-mentioned information can also affect the measurement of plants, preparation costs, energy conversion, and fuel utilization [8].

Several studies have been conducted on energy analysis and exergy of driers, some of which are as follows. Erbay et al. (2011) performed a study on the drying process of the olive leaf in a tray dryer, concluding that the highest amount of energy used for drying olive was 0.756 kW and the maximum exergy loss was 0.027 kW [9]. In a study on starch, Aviara et al. (2014) stated that energy utilization and exergy loss promoted by increasing temperature and reported the highest amount at 60 °C [6]. In addition, in their research on the pomegranate products concerning the microwave impacts, Minaee et al. (2012) reported that exergy loss and energy utilization in a thin-layer drying declined by the passage of time [10]. Basirat Tabrizi et al. (2015) carried out the drying process on paper in a convective dryer based on the first law of thermodynamics, reporting that the intake air temperature had a significant effect on exergy loss and exergy efficiency [11].

By studying peas and beans based on the first law of thermodynamics, other researchers, including Karaguzel et al. (2012), calculated energy utilization and exergy loss to be 0.105e1.949 kJ/s and 0.206e1.612 kJ/s, respectively [12]. Fluidized bed drying, among other drying methods, has many advantages, including high intensity of drying, high thermal efficiency, uniformity in drying, precise temperature control in the bed, as well as short drying time due to high rates of heat and mass transfer [13]. Sazzat Hossain Sarker et al. (2015) dried rice product in an industrial fluidized bed dryer, and the energy utilization ranged between 38.91 and 132 kJ/s [14]. Drying is an energy-consuming process; given that the energy utilization is 10%–15% of total energy utilization in all industries in developed countries, the engineering features are of utmost importance in the drying processes [2].

Nikbakht et al. (2014), in assessing the effect of microwave-assisted thin-layer dryer on pomegranate by neural network and response surface methodology, found that exergy productivity increased along with time. According to the results of the analysis of modeling, the models of ANN and RSM have demonstrated a reasonable performance in the prediction of parameters considered for dryer as a measure of energy and exergy. The value of the coefficient of determination ($R^2$) was acceptable in both models and emphasized the ability of ANN to predict unknown data with little knowledge of the nature of the problem [15].

Nazghelichi et al. (2011) predicted the drying kinetics of carrot cubes with dimensions of 4, 7, and 10 mm through fluidized bed dryers by using neural networks. The inlet air temperatures were 50, 60, and 70 °C, and the depths were 3, 6, and 9 cm. At first, the static ANN was applied and its outputs (relative humidity and the speed of drying) were related to four exogenous inputs (drying time, drying temperature, the size of the carrot cubes, and the depth of the bed). In artificial neural networks, in addition to four external inputs, Nazghelichi et al. applied state inputs and outputs (relative humidity or speed drying). They also reported that recurrent artificial neural networks, compared to static artificial neural networks, had higher values of $R^2$ in prediction [16].

Karimi et al. (2012) optimized air drying process for *Artemisia absinthium* leaves through response surface and artificial neural network model. The dependent variables were the response of moisture content, drying rate, energy efficiency, and exergy efficiency. They employed rotatable central composite design in response surface methodology to develop the model as a suitable method for response. The optimum conditions obtained from artificial neural network model included moisture of 0.15 g/g, drying rate of 0.35 g/h, energy efficiency of 0.73, exergy efficiency of 0.85, air temperature of 47.3 °C, air speed of 0.906 m/s, and drying time of 10.35 h in the coding unit [17].

Jena et al. (2013) examined the drying mushrooms and vegetables in a fluidized bed dryer. The parameters were temperature, air surface drying time, speed, and ratio of sample. Based on experimental data, they studied the effects of parameters in system on penetration of the samples and developed empirical relations for various samples through regression and artificial neural network analyses. In addition, they calculated the penetrations via both methods and compared them with the experimentally measured values. In the end, they indicated that there is a very good approximation as a result of the extensive application of correlation developed for industrial uses [18].

Nazghelichi et al. (2011) found the final optimization of ANN model by integrating RSM and GA and successfully obtained the relationship between input and output parameters. The integrated GA and RSM approach in their research demonstrated that GA and RSM are useful tools to find the optimal topology of artificial neural networks to predict energy and exergy through fluidized bed drying [19].

Kashani Nejad et al. (2009) employed Multilayer Perceptron Network (MLP) neural network and radial basis function (RBF) to estimate grain moisture during soaking. Moreover, they applied artificial neural networks to model soaking wheat seeds at different temperatures and compared the results obtained from Page's model. Soaking temperature and time were utilized as input parameters and relative humidity as output parameter. They also exercised MLP neural network model to describe the features found in wheat seed soaking [20].

The main purpose of this study was to conduct the thermodynamic analysis for drying of potato cubes in fluidized bed dryer under different conditions such as depth of bed, air speeds, and temperatures for energy and exergy analyses. We also aimed to obtain the best conditions for industrial uses, contribute to producing intelligent control devices through employing artificial neural networks in this type of dryers, and determination of the best conditions for drying the products.

## 2. Materials and methods

### 2.1. Material preparation

Freshly harvested potatoes were purchased from a local market and stored in a laboratory refrigerator at 5 °C. At the beginning of each test, the potatoes were washed, peeled, and cut manually by a cubic device with dimensions of 0.6 × 0.6 cm and a height of 0.5 cm. The drying experiment was conducted, using a laboratory fluidized bed dryer made in the Department of Mechanical Bio-systems of Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

### 2.2. Experimental procedure

To supply the required air flow, a centrifugal blower with a 3hp CDF90L_2 three-phase electric motor (KAIJIELI) was used. For outlet temperature measurement, an ST_941 standard multi-meter with an accuracy of ±0.1 °C was employed. To measure the wind speed of the dryer, an anemometer (LUTRON, AM-2416) with an accuracy of 0.1 m/s was utilized. The dryer contained an automated temperature controller with an accuracy of ±1 °C (Fig. 1). The samples were weighed every 5 min, using a Dj 2000A weight scale (Shinko electric scale) which had an accuracy of 0.01 g. During drying, the outlet air temperature of the dryer and the airflow ratio were recorded at 5-min intervals.

The samples were weighed at the beginning. After the dryer

Please cite this article in press as: Azadbakht M, et al., Application of artificial neural network method to exergy and energy analyses of fluidized bed dryer for potato cubes, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.12.006