Mechatronics 000 (2016) 1–14

Contents lists available at ScienceDirect

Mechatronics

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

Design, development and control of a portable laboratory for the chili drying process study

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ARTICLE INFO

Article history:
Received 7 October 2015
Revised 26 April 2016
Accepted 16 May 2016
Available online xxx

Keywords:
Chili drying process
Control, dryer
Graphical user interface
Modeling and simulation

ABSTRACT

Agricultural products such as chilies generally require drying for preservation. Traditionally, the chili drying process has been accomplished by burning fossil fuels in ovens or by open air drying. However, this process leads to severe losses in the quality and quantity of the final product. In this paper, a portable laboratory has been designed, developed and controlled using a mechatronic design philosophy in order to facilitate the chili drying process study. This portable laboratory can simulate different drying conditions under a controlled environment in order to find the best drying parameters for different kinds of chilies. Their computer based intelligence can monitor and control temperature, humidity, air flow, electric current and weight through a graphical user interface (GUI). The modeling and control technique of the system is described in detail. Simulation results using the mathematical model and experimental results under different drying conditions are presented to demonstrate the high performance of the portable laboratory and its great potential.

1. Introduction

Drying is defined as the process to remove water by evaporation from a solid. This process is often used for food preservation and allows reducing production costs in agricultural products [1]. In the most common case, a source of heat applies heat by convection and carries away the vapor as humidity. In most of the developing countries, the use of fossil fuels in the drying process is not feasible due to high costs of production [2]. The production cost in terms of thermal energy represents a significant fraction of the total drying cost especially in the case of convective dryers. Even though almost 100% of energy contained in the fuel is converted into drying air, the heat losses reduce the overall thermal efficiency up to 60% or less.

Open sun drying is the most traditional method practiced in rural areas by farmers. Such drying leads to severe losses in the quality and quantity of the product due to climate conditions, contamination, inadequate drying, fungal growth, encroachment of insects, birds and rodents [3]. A solar dryer is a device designed to reduce crop losses and improve the quality of the dried product compared to traditional drying [4–5]. Therefore, the development of solar dryers provides a sustainable alternative for the drying of agricultural products in developing countries. The principal aim of such devices and systems is to provide the best product quality with a minimum energy consumption [6]. The average of drying time using a solar dryer takes from 1 up to 3 days depending on climate conditions and the type of food to be dried. A large number of different kind of solar food dryers have been proposed [7–12]. The mechanical design of solar dryers is determined by their configurations, capacities, drying characteristics, energy efficiency and economic considerations [13]. Also, to ensure the final product best quality, it is important to control and monitor the temperature, humidity and air flow [14].

Chili (*Capsicum annuum L.*) is one of the most commonly consumed vegetables in Mexico [15]. It is consumed both fresh or as a dried product. The chili drying process is difficult to carry out without the correct drying parameters such as temperature and air flow [16–18]. This drying process removes humidity from the chili when the hot air flow passes over it. However, this process requires a constant supervision of the temperature and humidity during the drying [19–20]. If the air flow is warmed up, then the amount of moisture remains stable, but the relative humidity falls down [21]. A high-quality of dried chili is obtained when the temperature, air flow and drying time is controlled using the best dry-

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http://dx.doi.org/10.1016/j.mechatronics.2016.05.003
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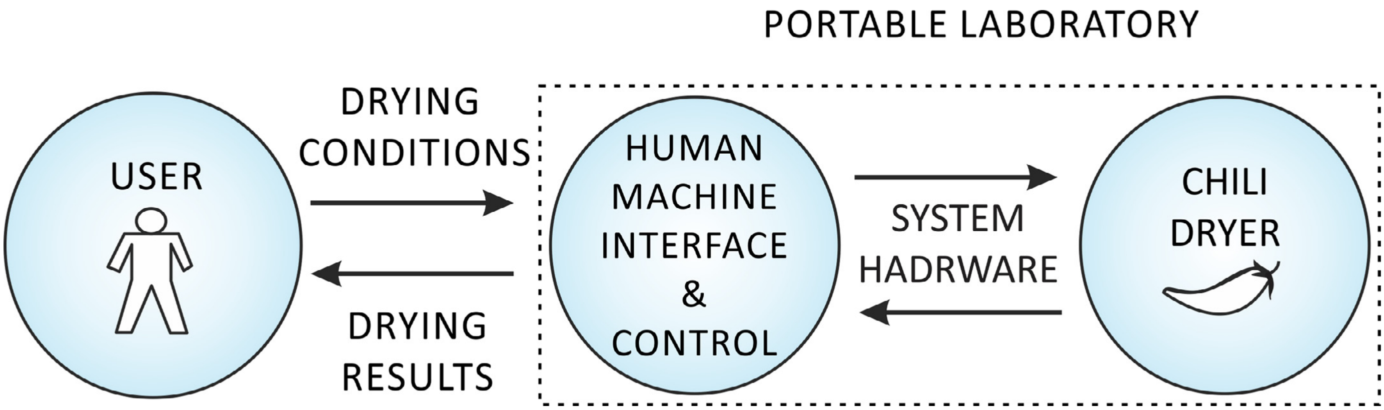

Fig. 1. System concept.

ing parameters [22]. One of the main objectives in the chili drying process is to achieve a uniform and stable temperature inside the dryer [23–24]. Nowadays, the development of sustainable energy systems such as the chili dryers is an interesting technology due to their potential benefits to the environment [25].

Chili dryers are developed to reduce the drying time and improve the quality of chilies [26]. These dryers can be classified in natural and forced convection [27]. The natural convection dryers are low-cost and do not require electric power during operation. Hossain et al. [28] present a natural convection solar dryer system for chili drying. Papade and Boda [29] and Kamble et al. [30] propose a natural solar dryer with energy storing material. Ibrahim et al. [31] present a natural solar dryer with an external oven. Fadhel et al. [32] present a comparison of chili drying between open air and a greenhouse drying. The forced convection dryers are generally more effective and controllable to provide the optimum drying condition. Mohanraj and Chandrasekar [33] develop a forced convection solar dryer with a heat storage material unit. Sundari et al. [34] present a solar dryer with an evacuated tube collector. Banout et al. [35] propose a double-pass solar dryer for drying red chili. Marnoto et al. [36] investigate the characteristics of a dryer using a heat pump dehumidifier (HPD). Hirunlabh et al. [37] develop a dryer that uses waste heat from a geothermal power plant. Charmongkolpradit et al. [38] and Cortés et al. [39] investigate the drying characteristics of chili using a continuous fluidized-bed dryer. Tunde-Akintunde [40] presents a mathematical modeling of chili drying using solar energy. Hudakorn and Katejanekarn [41] study a solar dryer with a square-corrugated air collector with attached internal fins for red chili drying. Paul and Singh [42] report a review of solar dryers developed for chili drying. Prakash and Satyanarayana [43] develop a solar drying system for the Guntur chili. Kaewkiew et al. [44] study the performance of a large-scale solar dryer greenhouse for chili drying. Kaensup et al. [45] perform an experimental study on chili drying using a microwave-vacuum system. Kaleemullah and Kailappan [46] present the drying kinetics of red chilies in a rotary dryer. In [47-50] the solar tunnel dryer performance is studied for chili drying. Other simple forced convective solar chili dryers are proposed in [51-52].

A great deal of research has been conducted on the basic designs of solar dryers, but few prototypes have been carried out with a degree of computer based intelligence to control and monitor physical variables such as temperature, humidity, air flow, electric current and weight through a graphical user interface (GUI) to identify the best chili drying parameters. The main objective of this research is to design, develop and control a portable laboratory for the chili drying process study in order to simulate different drying conditions under a controlled environment. The presentation of this paper is structured as follows: Section 2 contains the description of the portable laboratory. Section 3 shows the simulation results using the mathematical model. Section 4 shows the experimental results under different drying conditions. Finally, Section 5 concludes the paper.

2. Description of the portable laboratory

This portable laboratory is a device designed under a mechatronic approach in order to create a multidisciplinary system which integrates mechanics, electronics, computer systems and control. The architecture of the device is divided in four main parts: chili dryer, system hardware, human-machine interface and control, see Fig. 1. The prototype design and manufacture are explained below.

2.1. Chili dryer

The designed and developed chili dryer is shown in Fig. 2. The mechanical design of the chili dryer is based on the forced convection heat transfer theory [53]. The overall dimensions of the physical device are 1.46 m (length) x 0.5 m (width) x 0.4 m (height). The dryer's walls are selected 1 mm thick steel. The entire chamber is thermally insulated with a layer of fiber glass (2.5 cm of thickness). The thermal conductivity of fiber glass is 0.04 W/mK. The chamber of the dryer can handle temperatures up to 250°C. The air inlet of the dryer consist of a square diffuser with an angle of 45° which distributes uniformly the temperature inside the drying chamber. The diameter of the air outlet tube is 0.1 m. The system is equipped with a large metal tray (0.6×0.3 m) inside the chamber to support samples from 0.1 kg up to 3 kg of weight. The force sensor is located above the chili dryer using two aluminum rails in order to isolate it from the chamber.

The overview of the chili dryer components are shown in Fig. 3. There are two fans (a) located inside the chili dryer. One at the entrance and the other one inside the chamber. There are three temperature and humidity sensors installed (b). The first one is located inside the inlet tube, the second one inside the chamber and the third one inside the outlet tube. Also five temperature sensors (f) are located inside the chamber. The air flow sensor (c) is located after the first fresh air inlet fan. The electric resistance heater (d) is located after the square diffuser. The emergency stop (e) is installed in front of the drive system (j). The metal tray (g) is connected to the load cell (i) by using a rod (h). The computer (k) is connected with the chili dryer by using a USB cable. The wheels (l) of the dryer are installed at the bottom to facilitate transporting and handling.

Please cite this article as: C.H. Guzmán-Valdivia et al., Design, development and control of a portable laboratory for the chili drying process study, Mechatronics (2016), http://dx.doi.org/10.1016/j.mechatronics.2016.05.003