Renewable Energy 93 (2016) 77–86

Contents lists available at ScienceDirect

Renewable Energy

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

Drying of sweet basil with solar air collectors

Fevzi Gulcimen [a], Hakan Karakaya [b,*], Aydın Durmus [c]

[a] Tunceli University, Department of Mechanical Engineering, 62020 Tunceli, Turkey
[b] Batman University, Department of Energy Systems Engineering, 72060 Batman, Turkey
[c] Ondokuz Mayıs University, Department of Mechanical Engineering, 55139 Samsun, Turkey

A R T I C L E I N F O

Article history:
Received 7 August 2015
Received in revised form
7 February 2016
Accepted 10 February 2016
Available online 27 February 2016

Keywords:
Sweet basil
Solar drying
Mathematical modelling

A B S T R A C T

In this study, sweet basil was dried and its drying parameters were investigated experimentally and theoretically by using newly developed solar air collectors. Proper temperatures were chosen to dry sweet basil and experiments were carried out at different flow rates. At the end of drying experiments, it was determined that total mass of sweet basil decreased from 0.250 kg to 0.029 kg. In drying sweet basil, dimensionless moisture ratios were decreased rapidly to 300 min for 0.012 kg/s, 360 min for 0.026 kg/s, and 450 min for 0.033 kg/s. It was observed that the efficiency of collector was increased at the same rate with air flow changed between 29 and 63%. Among the models in the literature, Page Model was found to suit best for drying sweet basil. Furthermore, a novel mathematical model rendering more valid results for sweet basil and leafy products was developed.

1. Introduction

Temporary and permanent preservation methods have been implemented in order to store foods for centuries. Temporary methods can be outlined as cooling foods or storing them in fridges or isolating them from moisture and air. On the other hand, drying is the best example for permanent or long lasting preservation method.

Drying is the procedure that was defined as removing water or moisture from substances. Food drying is also a process to make fruits and vegetables last longer time by reducing the amount of water they contain from 80–90% to 10–20%. Therefore, drying can be defined as decreasing the amount of moisture since this process reduces the amount of moisture in products to such a level that they can be preserved against decay.

Today, of the driers used commercially, none provides completely the most economical and the best quality for drying facilities altogether. Each method has some limitations and deficiencies in terms of power consumption, drying cost and quality variables in products. Todays' commercial driers are designed to use one or a few methods such as contact drying, convective drying, drying with radiation, dielectric drying, and freeze drying, osmotic drying and vacuum drying. Among drying methods, today, the most commonly used one is the convective drying method carried out with the help of air flow. To heat the air in dryers, various types of energy sources (electric, LPG, fuel oil) are still being used in industry. Since utilizing commercial power sources in heating air increases the expenses of drying, this method is mostly not economic in drying fruits and vegetables in rural areas. For this reason, in many parts of the world, for heating air, solar power dryers have been developed utilizing solar energy in order to dry vegetables and fruits.

Drying method by means of solar power is divided into two major groups as passive and active method according to air circulation technique in dryer. In passive dryers, air circulation is activated by means of thermal power (according to the "Principle of Convection"). In active dryers, air circulation is provided by means of an electric fan. Although active dryers facilitate a faster drying compared to passive dryers, they cannot be used in places where there is no electricity, which necessitates an additional cost. Active dryers should be preferred when product to be dried is in a large amount; and when the drying period is short. Solar power dryers are classified as direct, indirect and combined types according to the forms of exposing to solar radiations [1].

The products dried by researchers can be categorized into two groups. While, in the first group, the leafy products such as mints, basils, vine leaves having thin structures and containing less moisture take place, in the second group, fleshy products such as apples, apricots, mulberries, potatoes containing more moisture

* Corresponding author.
E-mail addresses: hakan.karakaya@batman.edu.tr, hkarakaya@hotmail.com (H. Karakaya).

http://dx.doi.org/10.1016/j.renene.2016.02.033
0960-1481/

Nomenclature

I	Total radiation coming on tilted plane (W/m^2)
L	thickness of dried product (m)
M_e	Dry mass of product (kg)
M_o	Initial mass of product (kg)
M_t	Mass of the drying product at a time t (kg)
M_w	Water mass in product (kg)
n	Coefficient number in model used
(EF)	Sufficiency parameters (−)
(RMSE)	The root mean square error (−)
k	Drying constant (1/s)
t	Time (s)
$\dot{m}$	Mass flow rate of air (kg/s)
MR	Moisture ratio (−)
WT	Total error stemming from heat measurement (°C)
Wt	Total error stemming from time measurement (min.)
Ww	Total error stemming from loss of weight (gr)
WV	Total error stemming from speed measurement (m/s)
WM	Total error stemming from moisture measurement (rH)
WP	Total error stemming from pressure measurement (mbar)

Subscripts

c,i	Drier inlet
c,o	Drier outlet
cr	Crop
e	environment
exp	experimental
i	inlet
m	mean(Average)
n	number of experiments
nk	number of constants in the model
o	outlet
s	surface of collector
t	time
the	theoretical

take place. When these two groups of products are compared, fleshy products have disadvantages in decaying not only in terms of time but also in quality of product (colour, texture etc.). Researchers have designed various solar air power collectors to dry these products more efficiently. A. Hobbi studied various passive heat enhancement devices that include twisted strip, coil-spring wire and conical ridges. The comparison did not produce any tangible differences in the heat flux of the collector fluid [2]. B.M. Ramani proposed double pass counter flow solar air collector with porous material in the second air passage which is one of the most significant and remarkable design improvements that has ever been offered to better the thermal performance. Comparison results reveal that the thermal efficiency of double pass solar air collector with porous absorbing material is 20–25% and 30–35% higher than that of a double pass solar air collector without porous absorbing material and single pass collector respectively [3]. A.M. El-Sawi carried out an experimental study of two types of flatbed solar air collectors with flat plate and chevron pattern absorbers to investigate their performance over a wide range of operating conditions [4].

Designing different collectors, Durmus et al. performed several experiments on drying [5,6]. In a study that Akbulut conducted, he dried mulberries in Elazıg region and investigated drying parameters [7]. In another study, Akbulut investigated energy and exergy analyses of redpeppers dried in thin layers [8]. Koua et al. investigated the behaviour of thin layer drying of plantain, banana, mango and cassava experimentally in a direct solar dryer, and secondly performed mathematical modelling by using thin layer drying models present in the literature [9]. Doymaz studied the effects of air temperature, air-flow rate and sample thickness on drying kinetics of carrot cubes. In the studies he carried out, convective air drying characteristics of carrot cubes were evaluated in a cabinet dryer [10]. A.Kouchakzadeh tested a new approach of ultrasound-assisted sun drying. In this study, he used a flatbed as product support and two extensional piezoelectric Bolt-clamped 20 kHz transducer elements. Wet unshelled pistachios with mono layer were dried under the sun by applying 500 and 1000 W power ultrasound [11]. Özdemir and Devres tried to explain the drying characteristics of hazelnut on a thin layer between the temperature clearances of 100 °C–1600 °C [12]. Akpınar investigated thin-layer drying characteristics of mint leaves in solar dryer with reinforced convection; and under the sun with natural convection with the purpose of carrying out energy and exergy analysis of solar drying process of mint leaves [13]. Yaldız and Ertekin modelled drying of the seedless sultana raisins as thin layers by means of solar power dryers. Drying air is heated with the help of solar power air heater; and drying process was conducted by allowing the heated air to pass among the product on the shelf in drying chamber [14]. Togrul investigated the effect of drying temperatures on drying ratios of apple slices at different temperatures. When drying temperatures were increased from 500 °C′ to 800 °C, he determined that drying ratios also increased almost twice [15].

Tripathy proposed a methodology for determination of temperature dependent drying parameters, which are drying constant and lag factor of the experimental drying kinetic curves of food product [16]. The drying systems were evaluated thermodynamically by researchers, and also energy and exergy analyses were carried out [17–20].

During the drying process, a constant mass and heat transfer occur. It is very important that the parameters of this complex process be understood better in terms of engineering. Mathematical modelling of drying process can be used both for designing and improving new drying systems and for controlling drying process. The parameters such as drying air temperature and speed used in these models directly depend on drying conditions. In order to define drying processes, a number of mathematical models were developed and many products were examined [21–24].

In this study, a solar air power cabin dryer collector was designed in order to dry sweet basil, frequently used in soup, salad, meals and beverages in daily life healthily, without damaging its physical properties. A cabin type dryer was designed in the study with authentic solar air collectors in order to benefit from sun more efficiently. It has low first investment expenses and is capable of eliminating drying defects on a large scale. After the experiments at different flow rates and specified temperatures in accordance with sweet basil, drying parameters were investigated experimentally and theoretically; and the obtained results were compared to the literature. In addition, the convenient model for sweet basil was determined after this model was compared to drying models previously developed; and a novel mathematical model was developed to be able to use for drying leafy products.