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Experimental investigation of a new design solar-heat pump dryer under the different climatic conditions and drying behavior of selected products

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Abstract

The purpose of this research paper is to perform experimental analyses of system in drying of various agricultural products under different climatic conditions. The secondary goals are to keep a constant drying air temperature with PID, to obtain a homogeneous temperature in the drying chamber to determine the effects of PID control on the system, and to evaluate the drying behavior of various products at 50 °C a with variable mass flow rate for a drying analysis. Heat energy requirements were provided with new type double-pass solar air collector (DPSAC) and the heat pump (HP) unit while electricity energy requirements were provided with a photovoltaic (PV) system. The coefficients of performance of the whole system (COP_{WS}) for experiments of tomato, strawberry, mint, and parsley were calculated as 1.96, 2.27, 2.28 and 2.17, respectively. The average thermal efficiency of DPSAC was between 16% and 79%. Specific moisture extraction ratio value for the whole system ($SMER_{WS}$) was varied between 0.03 kg/kW h and 0.46 kg/kW h for the products. Energy utilization ratio (EUR) was obtained between 0.19 and 0.48. Results demonstrated that the HP unit, DPSAC, PV unit and PID control system can work in coordination with each other and was obtained dried products having good physical properties at the same time.

Keywords: Drying; Double-pass solar air collector; Heat pump; Performance analysis

1. Introduction

Turkey is a major producer of tomato, strawberry, mint, and parsley. At the same time, it is a major consumer of these products. According to FAOSTAT, Turkey was one of the largest producers of tomatoes and strawberries in 2011 (FAOSTAT, 2011). The tomato is usually consumed fresh: however, it can be evaluated in different forms; tomato paste, sauce, ketchup, tomato juice, tomato puree, and canned. Drying tomato is traditionally carried out using sun-drying techniques in Mediterranean countries. In order to improve the quality of dried tomato products industrial drying methods, such as, hot-air and solar drying are adopted (Doymaz, 2007). Strawberries may be used as fresh, juice, in concentrated jam, in jelly, or dry and rehydrated with yogurt and bakery products (El-Beltagy et al., 2007). Today dried foods are presented to the consumer in a variety of forms snacks, dry mixes, soups, and dried fruits (Krokida et al., 2003). Parsley is an aromatic plant, which is widely used in culinary and medicinal areas. The fresh or dried leaves, roots, and seeds of this plant are used to produce spice, essential oils and

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Nomenclatures

A	area, m^2
c	specific heat, kJ/kg K
dt	measuring the time interval, min
h	enthalpy, kJ/kg
I_{TOT}	instantaneous total radiation on a horizontal surface, W/m^2
M_i	initial wet weight, g
M_d	final dry weight, g
M_t	moisture content at time "t", g water/g dry matter
M_{t+dt}	moisture content at "$t + dt$", g water/g dry matter
M_e	equilibrium moisture content, g water/g dry matter
M_0	initial moisture content, g water/g dry matter
m	mass, kg
$\dot{m}$	mass flow rate, kg/s
$\dot{m}_{Water}$	the mass of water taken from product, kg/h
$\dot{Q}_{sc}$	capacity of collector, kW
$\dot{Q}_C$	condenser capacity, kW
R	the function uncertainty
T_{in}	outside air temperature, °C
T_{out}	collector air outlet temperature, °C
t	time, min
U	heat loss coefficient, W/m^2 K
$\dot{V}$	volumetric flow rate of air, m^3/s
$\dot{W}$	energy utilization, kW
$\dot{W}_{Comp}$	power input to compressor, kW
$\dot{W}_F$	power input to fan, kW
$\dot{W}_P$	output power of photovoltaic cell, W
W_R	the total uncertainty, %
W_r	weight after rehydration, g water
W_d	weight of dried material, g dry matter
w_1, w_2, w_n	the uncertainties in the independent variables
x	independent variables
η	efficiency, %
ρ	density, kg/m^3
φ	relative humidity, %
ω	specific humidity, kg water/kg dry air

Subscripts

EUR	energy utilization ratio
DR	drying rate, g water/g dry matter min
MC	moisture content, g water/g dry matter
MR	moisture ratio, M/M_0
SMER	specific moisture extraction rate, kg/kW h
PID	proportional–integral–derivative
COP	coefficient of performance
HP	heat pump
ia	inlet air
aai	ambient air inlet
C	condenser
cv	convection
d	dryer
dc	drying cabinet
E	evaporator
e	exhausted
L	lost
mp	moisture production
oa	outlet air
p	plate
sc	solar collector
ws	whole system

drugs in food for the cosmetic and pharmaceutical industries. At the same time the fresh parsley leaves are used as a garnish (Akpinar et al., 2006). Mint is also widely used in the food, flavoring, pharmaceutical and cosmetic industries. Additionally, it is used as a useful ingredient for soothing effect in pharmaceuticals (Albaugh et al., 2002). The Mint leaves and stalks are known to be good digestive aids and mint is used as a component of many drugs (Park et al., 2002).

Products are dried for long-term storage. Drying is a crucial process in preserving plants to make them available to consumers during the whole year; however, the drying process is affected by many factors. Factors affecting efficiency of drying are: air temperature, air velocity, product type, thickness of the product, initial and final moisture content of the product, method of drying, temperature and moisture diffusivity, air movement and the drying cabinet structure (Şevik, 2011). Therefore, different dryers are used in drying applications. Considerations, such as, the water activity value, amount of aflatoxin, aroma, color, and the shelf life should be considered during and after drying.

Solar energy systems are extensively used in drying applications due to their easy implementation and simple technology. They can be used directly or indirectly in drying applications. The structural aspects of solar dryers consist of the greenhouse, the collector, and the heat pump assisted. Solar air collectors (SACs) are used as a single-pass solar air collector (SPSAC), a double-pass solar air collector (DPSAC) or a multi-pass solar air collector (MPSAC). SACs are used in space heating (RETScreen, 2004), product drying (Karim and Hawlader, 2004), greenhouse heating (Benli and Durmuş, 2009), and for pre-heating in ventilation systems (Sokhansanj and Schoenau, 1991). Recent studies related to different type collectors have been undertaken by several researchers