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Investigation of different parameters and study of mixed-mode forced convection solar dryer equipped with a PV/T air collector

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A R T I C L E I N F O

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Drying tomatoes
Relative humidity

A B S T R A C T

The current paper presents an experiment and an examination of the performance of a mixed solar dryer with forced convection, which has been used to dry tomatoes. Generally, the air flux enters in the aluminium tubular canals located under the PV panel and spreads simultaneously into an upper gap. Further, it provides heat exchange in both faces of the panel PV which helps to cool the photovoltaic cells and to carry the thermal energy to the drying room. This grants them the chance to conserve the dried tomatoes for longer periods and to reduce the loss of crops. Furthermore, it supplies more electrical energy supplies for the rural areas. Tomatoes were divided into two trays and dried with the forced convection mixed solar dryer. Then, a comparison was established with a naturally dried sample. This realized prototype, product moisture content dropped from 91.94 (%) to 22.32 (%) for tray 1 and to 28.9 (%) for tray 2, by against it dropped only to 30.15 (%) for open sun dryer. I is found that the drying temperature is improved and the quality is enhanced.

1. Introduction

The sun is the major source of alternative energy. It is in fact, preferred to other energy sources because it is inexhaustible and non-polluting (Kavak Akpinar, 2010). Tunisia is situated in the Mediterranean region. It receives between 2860 and 3200 h of sun a year (Elkahdraoui et al., 2015). This important amount of energy can be used in many different ways among which drying agricultural products. One of the main problems in Tunisian rural regions is food conservation due to electricity scarcity. Farmers mainly use drying as solution to preserve several agro-food products such as tomatoes, chilly, medicinal plants, etc. They mainly use the direct exposition of these products to the sun and that may cause their quality degradation due to dust, UV, etc. Drying is one of the most important solutions of food preservation. It has been extensively researched in the past few years. Hence, this field takes considerable importance and there is also a need to improve and develop it to the highest extent possible.

There are different designs and shapes of solar dryers for agricultural products (Sharma et al., 2009). They are classified according to the drying methods (El-Sebaii and Shalaby, 2012): (1) open sun drying (OSD), is the oldest method, (2) direct solar drying (DSD), (3) indirect solar drying (ISD), and (4) mixed solar drying (MSD). In the OSD method, the product to be dried is spread over thin layers and directly exposed to solar radiation on the ground or on the rack (Mustayen et al., 2014). The time required to reduce the moisture content of the product in open sun is long and the product can be deteriorated by rainfall, animals and insects (Kavak Akpinar et al., 2003). Consequently, the final quality and quantity of the dried products are very far from the international standards and therefore, they cannot compete in the international markets. Moreover, there is a need for an extensive manpower, and much physical space occupation (Basunia and Abe, 2001).

These drawbacks of OSD can be solved by using solar drying systems like DSD, ISD and MSD.

The efficiency of the solar dryer systems is higher than OSD (Navalea et al., 2015).

Jain and Tiwari (2003); studied the thermal performance of open sun drying by developing a mathematical model. Their results indicated that this drying method was very slow and had high loss and low quality. Since the OSD caused many problems, researchers are seeking

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List of abbreviations

A_c	surface area of solar collector (m^2)
C_p	specificity air heat capacity (J/kg °C)
G	solar radiation (W/m^2)
I	current (A)
P_e	electrical power (W)
P_{th}	thermal power (W)
PT_{100}	platinum probe
PV	photovoltaic panel
PV/T	photovoltaic-thermal solar collector
Q_c	useful energy gained from the collector (W)
q_m	mass flow rate (kg/s)
R_{ele}	electrical efficiency (%)
R_{th}	thermal efficiency (%)
T_a	ambient temperature (°C)
T_{int}	inlet temperature (°C)
T_{out}	outlet temperature (°C)
T_{pv}	temperature of the PV (°C)
T_{tray1}	temperature in the tray 1 (°C)
T_{tray2}	temperature in the tray 2 (°C)
T_{tube}	temperature in the tube (°C)
U	tension (V)
MSD	mixed solar dryer
OSD	open solar dryer
DSD	direct solar dryer
MR	moisture content (%)
M_i	initial weight (g)
M_f	final weight (g)
RH	relative humidity (%)
V_{int}	inlet velocity (m/s)
V_{tray}	velocity in the tray (m/s)
$W_{v\text{-}max}$	maximal wind velocity (Km/h)

other more effective solutions for open drying. They discovered direct solar drying system which is a simple frame of a glazed unit made of a single piece that includes both a drying room and a solar collector in which the products are placed on racks and protected from wind and dust. The sun rays directly hit the products through the transparent wall. However, the DSD presents some disadvantages such as (1) small capacity of the crop, (2) the required drying time is long, (3) the transitivity of the glass cover is reduced due to the evaporation of moisture and its condensation on the glass cover, and (4) overheating of the crop may take place due to the direct exposure to sun light, and the efficiency is low because a part of the solar energy input is used to induce air flow and the product itself acts as an absorber (Madhlopa et al., 2002; Banout et al., 2011). Turk and Pehlivan (2014) suggested a new method of using a direct solar dryer. They concluded that this type of dryer has some limitations. The product can for example, be discolored because of direct exposure to solar radiation. Besides, the moisture compression inside the glass cover decreases the sun rays' transitivity. The third type is the indirect solar dryers. They were developed worldwide and many conceptions had been proposed in order to improve the thermal efficiency of solar dryers. This mode consists of a drying chamber and a solar collector, in which the air is heated before entering the dryer chamber through a duct. Sharma et al. (1993) analyzed the performance of an ISD and concluded that this method could yield high quality products in even non-ideal environments. On other hand, Nabnean et al. (2016) studied the experimental performance of a new design of ISD for osmotically drying dehydrated cherry tomatoes. They concluded that the air temperature varied between 30 (°C) and 65 (°C) during drying, which was sufficient for osmotically drying dehydrated cherry tomatoes. The drying time for 100 (kg) cherry tomatoes was 4 days. As for Zhang and Long (2017), they determined that the performance of the solar dryer is dependent on the intensity of incident solar radiation on the collector surface and the ambient temperature. The fourth type of drying is the MSD, where the material to be dried is heated in two ways, through the direct absorption of solar radiation and at the same time by the air heated with the solar collector (Rittidech et al., 2005). Moreover, Zomorodian et al. (2007) constructed, studied and evaluated a mixed solar dryer to dry rice. They showed that their system has a satisfactory efficiency when the maximum performance was reported to be 21.24 (%). Furthermore, Doymaz (2007) studied the drying characteristics of tomatoes investigated at 55, 60, 65 and 70 (°C) with an air flow rate of 1.5 (m/s), and dried to the final moisture content of 11 (%) from 94.5 (%). The increase of the air temperature inthe range of 55 (°C) to 70 (°C), increased the drying rate of tomatoes. The research for the enhancement of the thermal productivity of the solar dryer system led to the gradual integration of the (PV/T) solarcollector into dryer. Many researchers studied and used the solar collector (PV/T). For instance, Tiwari et al. (2009) studied the perfor-mance of a conventional solar dryer integrated within the solar col-lector (PV/T). They deduced that the conventional PV/T mixed modedryer presented in this study is a self-sustainable system and verybeneficial for remote areas where the purpose of drying and electricitygeneration can be fulfilled simultaneously. As for Shahsavar and Ameri(2010), they showed that there is an agreement between experimentaland theoretical results for air mass flow rate, outlet air temperature andthermal efficiency, which increased with the increase of the air massflow rate. Setting a glass cover on photovoltaic panels leads to an in- crease of thermal efficiency and a decrease of electrical efficiency of thesystem. On their part, Sarhaddi et al. (2010) investigated the thermaland electrical performance of a solar photovoltaic thermal air collector(PV/T). They concluded that the overall energy efficiency of a (PV/T)air collector is always greater than the thermal efficiency of a solarcollector and the electrical efficiency of a PV module. When the inlet airvelocity and the solar radiation intensity increase, the overall energyefficiency and thermal efficiency of a PV/T air collector also increase. In the present study, a non-destructive modification was performed on a conventional photovoltaic panel incorporating an air heat ex- changer behind the PV recovering waste heat. The PV/T was directed to the south with the angle of 45 degrees from the horizontally to receive a maximum radiation. The air flux enters in the aluminium tubular canals located under the PV panel and spreads simultaneously into an upper gap. Consequently, it provides heat exchange in both faces of the panel PV which helps to cool the photovoltaic cells and to carry the thermal energy to the drying room. The main objective is to study the effec- tiveness of our prototype solar dryer in terms of drying time and pro- duct quality, as well as the thermal and electrical performance of the realized prototype of solar collector PV/T. Moreover, the present system improves the promotion of agro-food micro-enterprises by the integration of miniaturized machines in remote areas where the electric connectivity is not available. In these sites, the farmers can dry the various agriculture products using the prototype we have realized. Furthermore, this prototype provides an economic gain for farmers who previously used natural drying.

2. Conclusion

This paper reports an experimental investigation on the MSD with forced convection. The experiment shows that the added PV/T air collector improves the efficiency of the drying process. The initial moisture content of the tomatoes is 91.94 (%), and it dried to 22.32 (%) in the MSD within 44 h but in OSD it dried to 30.15 (%) within 44 h. The tomatoes dried faster in the MSD. The present system practically shortens the drying time. A gain of drying time is recorded. The MSD method has given interesting results concerning the thermal equili- brium. With reference to the results about the MSD and OSD, we con- clude that the drying time of tomatoes depends heavily on the mass of the dried product and the drying temperature. Furthermore, the quality of the product in an MSD is found to be considerably higher compared to the other drying techniques, making it feasible when compared to other techniques. Based on experimental investigation, it can be con- cluded that the food product size and the loading density have a sig- nificant effect on the moisture removal from the product as well as on the drying efficiency. The realized prototype allows the increasing of the photovoltaic cells efficiency by cooling cycle. Also, it enhances the performance of the drying process. Consequently, the duration of drying decreases and the quality of the product (color) is improved. In the future work, we will investigate in the heat recycling from the output air (counter flux heat exchanger). Also, a secondary source of heat will be realized in the insufficient solar radiation. The MSD with a heat power storage seems to be a better alternative which have to be investigated. Furthermore, we will develop a mathematical model of

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