3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)
Proceedings of Engineering & Technology (PET)
pp. 371-376

Investigation of a new solar greenhouse drying system for peppers

Zaineb AZAIZIA, Sami KOOLI, Amen Allah GUIZANI

Laboratoire des Procédés Thermique, Centre de Recherches des Technologies de l'Energie, Hammam Lif, B.P. 95, 2050 Tunis, Tunisia

azaiziazeineb@gmail.com
Samikooli2000@yahou.fr

***Abstract*—Solar drying is the oldest preservation technique of agricultural products using several types of solar crop dryers based mostly on solar energy, which is abundant, renewable and sustainable. This study aimed to modeling a new solar greenhouse drying system (SGDS) for the drying of red peppers. The proposed mixed-mode (SGDS) consists of two main parts, namely a flat plate solar air collector and an experimental greenhouse.A mathematical model is developed using the TRNSYS simulation program to predict the change in the drying kinetics during the drying process under our proposed (SGDS). The experimental part consisted in testing the solar air collector to investigate its performance. The test showed that this solar air collector has a good performance; its efficiency varies between 0,5 and 0, 65. The influence of the area of the product to be dried was studied, and to show its effect on moisture content changes and air temperature and humidity inside the greenhouse. The area of product was varied from 10 to 40 m^2. For the case study of this SGDS, the results obtained from simulation showed that the optimum values of area of the product to be dried were found to be 40 m². It's more suitable to dry all the quantity of peppers simultaneously.**

***Keywords*—** Solar greenhouse drier; solar air collector; TRNSYS; Simulation

I. INTRODUCTION

The greenhouse dryer is a system that uses the standard greenhouse structure to work as a solar dryer during the warmer months of the year, also the product will be completely protected from rain, dust, insects and animals during drying.It is a simple structure, large load capacity and relative good thermal performance. Various investigators have introduced the greenhouse for drying agricultural products such as. ELkhadraoui et al [1] studied and compared the thin layer drying characteristics of Sultana grape and red pepper in the new solar greenhouse dryer and under open sun.Farhat et al.[2] have proposed polyethylene greenhouse dryer under natural convection mode for the drying of pepper. This leads to more than an 83% reduction of mass of the pepper at the end of the drying process.Banout et al [3] presented a new design of a double-pass solar dryer (DPSD) for drying of red chilli and compare it to typical solar cabinet drier and traditional open-air sun drying technique. Janjai et al. [4] whom studied the experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. A system, of partial differential equations describing heat and moisture transfer during drying was developed and solved numerically using the finite difference method. A large-scale greenhouse type solar dryer for drying chilli with an area of 8×20 m^2 was studied by Kaewkiew et al [5] in order to investigate its performance compared with natural sun dried. A mathematical model was developed by Kooli et al [6] to simulate the greenhouse drying of red pepper.This model was validate with the experiments results at constant laboratory conditions and at varying outdoor conditions. Forson et al [7] introduced a mathematical model for drying agricultural products in a mixed-mode natural convection solar crop dryer .The governing equations of the drying air temperature and humidity ratio, the material temperature and its moisture content and performance criteria indicators were derived. Results of simulation runs using the model were presented and compared with the experimental data.Tunde et al [8] study the drying characteristics of chilli pepper by sun and solar drying and to develop a mathematical model for describing the thin-layer drying process for the sun and solar drying of chilli pepper. Dilip Jain et al [9] a mathematical model is devised to study the thermal behavior of a greenhouse while heating with a ground air collector (GAC) The model was validated experimentally in the climate of Delhi for the winter season. A computer program based on Matlab software has been used to predict the plant and room temperatures as a function of various design parameters of the ground air collector. Fadhel et al. [10] performed an experimental study to compare the thin layer drying characteristics of red pepper in the open-sun, under a greenhouse and in a solar drier. Inés[11] was developped a mathematical model for simulation of solar drying of grapes The model was validated with experimental field solar drying data and represents an advance for the accurate prediction of the drying of grapes. Karina et al [12] present a simulation model for air drying of red pepper, which takes into account the quality deterioration during the process, and the results showed that the rate constants increased with temperature and product moisture content.

In this study, a new solar drying greenhouse system (SGDS) consists of two mainly parts namely a flat plat solar air collector and a greenhouse was presented for drying red pepper.A mathematical model was developed using TRNSYS simulation program to predict the effect of the area of the product to be dried in drying kinetics and an experimental test of solar air collector to investigated its performance

II. MODELING OF THE SGDS ON TRNSYS:

The SGDS was modeled in TRNSYS fig 1 .The solar air collector has been modeled by a component TYPE1b. The greenhouse has been modeled by a multi-zone subroutine component TYPE56. This component models the thermal behavior of a building with multi-thermal zones. The solar air collector has been modeled by a component TYPE1b. The greenhouse occupy a floor area equal to 14.8 m^2, 3.7 m wide, 4 m long and 3 m high at the center. The greenhouse walls and roof are covered by plexiglass with 0.003 m of thickness. To exhaust the moist air from the greenhouse, it was equipped with two centrifugal fans. This drying system has a maximum capacity of drying 80 kg of peppers. It could accommodate four trays in stacks with a total drying area of 40 $m^2$and the dimension of one tray is 2.5 m×4 m.

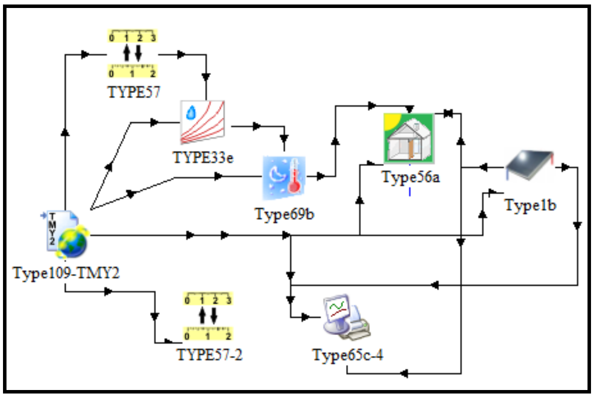

Fig.1 TRNSYS model of the solar dryer.

The heat transfer in the greenhouse are treated using the component Type 56.The exchanged flows between the greenhouse and its environment are presented in fig.2.

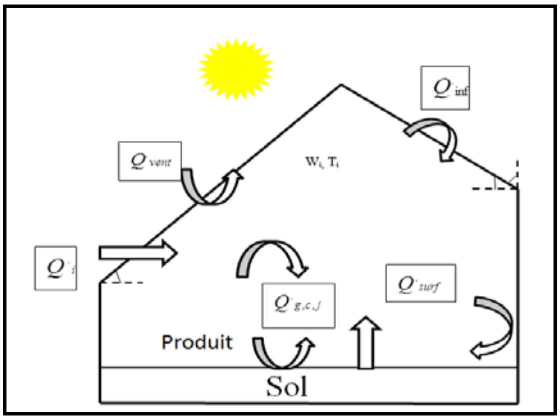

Fig.2 Heat and mass exchanges considered in the greenhouse

The sensible energy balance for an arbitrary building geometry is presented by the following equation

$$C_a \frac{dT_a}{dt} = \dot{Q}_{surf} + \dot{Q}_{inf} + \dot{Q}_{vent} + \dot{Q}_{gc} + \dot{Q}_{cplg} \qquad (1)$$

Here, the $\dot{Q}_{surf}$ is the total gain from all inside and outside surfaces , The $\dot{Q}_{inf}$ which is the total infiltration gains, The $\dot{Q}_{vent}$,ventilation gains produced by a user-defined ventilation system, The final two terms in Eq. (1) represent the internal convective gains due to the appliances and the occupants, $\dot{Q}_{gc}$ and the convective gains due to the coupling of zones $\dot{Q}_{cplg}$.

The moisture balance used in this model is presented by the following equation:

$$M_{eff,i} \frac{d\omega}{dt} = \dot{m}_{infl} (\omega_a - \omega_i) + \dot{m}_v(\omega_v - \dot{m}_i) + W_{g,i} \qquad (2)$$

Where $W_{g,i}$ is the internal moisture gain due to the moisture generated by the product (peppers)

A general equation for solar thermal collector efficiency can be evaluated by Klein et al. [13]:

$$\eta = \frac{\dot{Q}_u}{I_t A_{coll}} = \frac{\dot{m}_{coll} c_p (T_o - T_i)}{I_t A_{coll}} = F_R (\tau\alpha)_n - F_R U_t \frac{(T_o - T_i)}{A_{coll}} \qquad (3)$$

and it can be rewritten as

$$\eta = a_0 - a_1 \frac{(T_i - T_{out})}{I_t} - a_2 \frac{(T_i - T_{out})^2}{I_t} \qquad (4)$$

which is the general solar collector thermal efficiency equation used in TRNSYSY program (Type1b).

III. ANALYSIS OF COLLECTOR PERFORMANCE

An experimental test was performed in order to determine the characteristic parameters of the solar air collector fig3. The solar collector consists of insulator, absorber and cover glass. The length, the width and the total volume of the collector are 2 m, 1 m and 0.28 m^3, respectively. The 0.004 m thick transparent glass cover was placed 0.05 m apart from the absorber. The 0.001 m thick corrugated absorber was placed 0.04 m apart the insulator. The 0.05 m thick polyurethane insulation, with heat conductivity 0.028 W/m K, is placed in the bottom of the collector to decrease thermal losses through the bottom. There are two air gaps between cover glass and the absorber and between absorber and insulator through which ambient air is sucked by a centrifugal fan from lower side of the collector to the greenhouse. The solar collector was oriented full south and inclined 37° to horizontal plane. The test begins at 8:00 a.m (Local solar time) and finishes at the end of the solar journey at 17:00 p.m. These experiments were carried out for three ‘typical’ days on August characterized by clear sky with flow rates 0,026 kg/s , 0,052 kg/s and 252 kgh^{-1} respectively .

Fig.3 variation of efficiency with time for three flow rate

The main result of the experimental test is, the variation of the instantaneous efficiency of solar air collector for different flow rate fig.4, which present an average instantaneous efficiency 49% for ṁ= 0,026kg/s, 54% for ṁ = 0,052 kg/s and 64% for ṁ= 0, 07 kg/s. As we can see the instantaneous efficiency starts to decrease after reaching its maximum at 10:00 a.m despite the increased of solar radiation and the outlet temperature of fluid. This can be attributed to the increase of the heat losses and also to the thermal inertia of the solar air collector. As well, the evaluation of the instantaneous efficiency η changes Fig. 5, which is the ratio of the useful energy gain to the absorbed solar energy by the collector .These results, next, will be used in the simulation of the SDGS on TRNSYS.

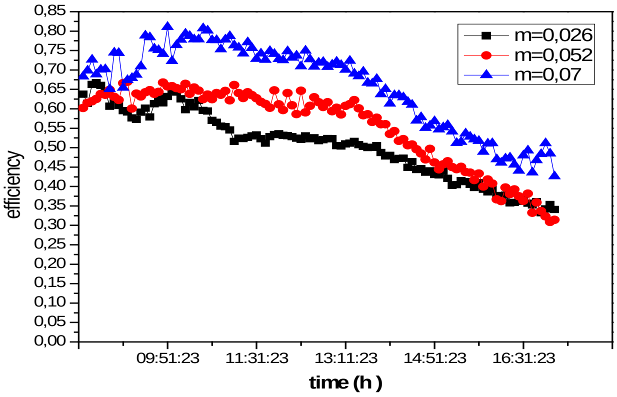

Fig4 : variation of efficiency with time for three flow rate

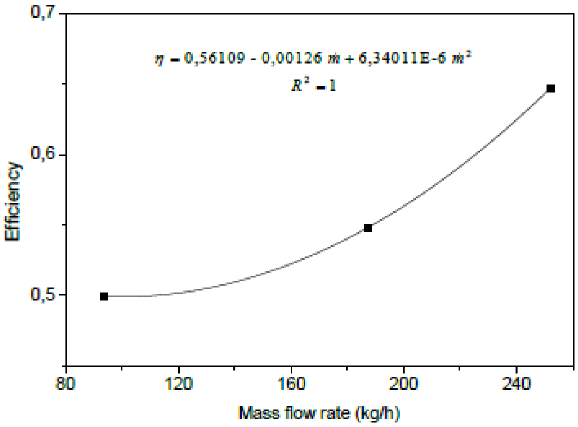

Fig. 5: The instantaneous efficiency changes of the solar air collector vs mass flow rate

IV. RESULTS AND DISCUSSION

The changes of moisture content with time during drying of pepper for four different areas of peppers are given in Fig 6. The increase of the area of peppers leads to a slowing down of water evaporation that is a decrease in drying speed and consequently the drying time increased. The SGDS takes 60 h to dry one tray of peppers, 96 h to dry two trays of peppers in stacks and 144 h to dry four trays of peppers in stacks. To dry 40 m² (maximum capacity) many possibility come up: one can dry four trays of peppers simultaneously or separately. The drying of 40 m² of peppers takes 144 h while drying it separately by tray takes 240 h and drying it separately by two trays in stacks takes 192 h. So, it’s more suitable to dry all the quantity of peppers simultaneously.

The changes of temperature inside the greenhouse with time during drying of pepper for different areas of peppers are given in Fig7. As can be seen an increase in the areas of peppers has no effect on the inside air temperature.

The changes of relative air humidity with time during drying of pepper for different areas of peppers are given in Fig8.As can be seen an increase in the area of peppers resulted in a significant increase in relative air humidity and consequently the evaporating capacity of the air decreased. For the first day of drying, an increase in the areas of peppers from 10 m^2 to 40 m^2 resulted in an increase at midday in relative humidity from 70 % to 100 %. The increase of the areas of peppers has outcome to give off more moisture air inside the greenhouse. The area of peppers is an influential parameter on the drying operation.

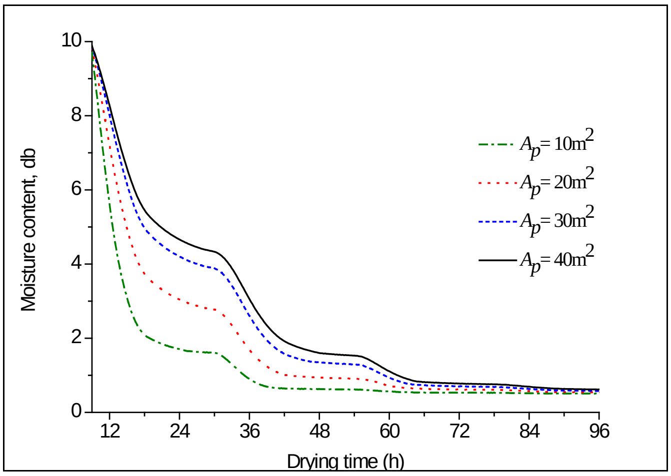

Fig. 6 Changes of moisture content with time during drying of pepper for four different areas of peppers

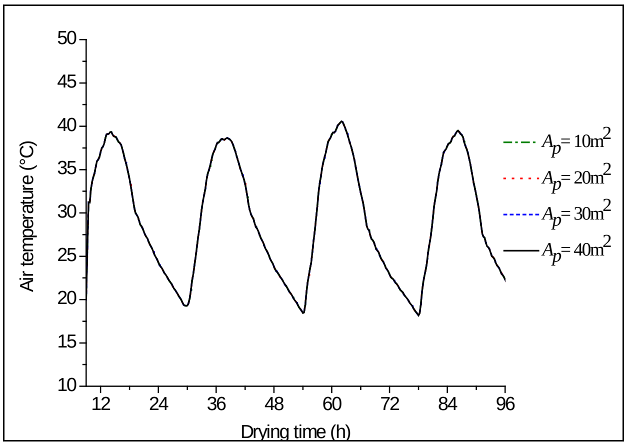

Fig. 7: Changes of temperature inside the greenhouse with time during drying of pepper for different areas of peppers

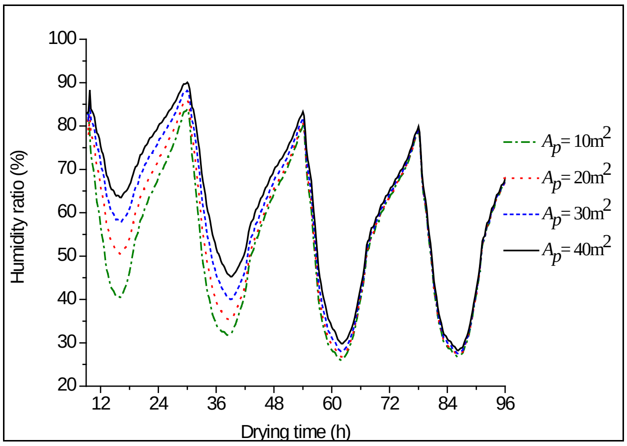

Fig. 8: Changes of air relative humidity with time during drying of pepper for different areas of peppers

V. CONCLUSION

The developed solar crop dryer is an alternative process to overcome the disadvantages of traditional open sun drying and utilization of maximum available solar radiations .In the present work, a new SGDS was modeled on TRNSYS program simulation which consists to study the effect of the variation of the product area to be dried on drying kinetics. An experimental test of the solar air collector was performed in order to study its effectiveness. The simulation results showed that the optimum values of area of the product to be dried were found to be 40 m² and the experimental test of the solar air collector showed that this collector has a good performance where its efficiency varies between 0, 5 and 0, 65.

Nomenclature

A	area, m^2
C_a	thermal capacitance of the zone air, J/K
c_p	specific heat of air at constant pressure, $J/(kgK)$
F_R	overall collector heat removal efficiency factor
I_t	total solar radiation on tilted surface, W/m^2
$\dot{m}$	mass flow rate kg/s
$\dot{Q}$	heat rate, W
T	Temperature, °C
t	time, s
U_t	loss coefficient, $W/(m^2K)$
W_a	Ambient air humidity
η	thermal collector efficiency
ω	humidity ratio
$(\tau\alpha)_n$	product of the cover transmittance and the absorber absorptance at normal incidence
a	greenhouse air
$coll$	collector
g	ground
i	inlet
inf	infiltration
o	outlet
p	product
$vent$	forced ventilation

REFERENCES

[1] Aymen ELkhadraoui ,Sami Kooli, Ilhem Hamdi, Abdelhamid Farhat , Experimental investigation and economic evaluation of a new mixed-mode solar greenhouse dryer for drying of red pepper and grape**,** Renewable EnergyVolume 77, May 2015, Pages 1–8

[2] Farhat A., Kooli S., Kerkeni C., Maalej M., Fadhel A., Belghith A. Validation of a pepper drying model in a polyethylene tunnel greenhouse. International Journal of Thermal Sciences 43 (2004), 53-58

[3] J. Banout , P. Ehl , J. Havlik , B. Lojka , Z. Polesny , V. VernerDesign and performance evaluation of a Double-pass solar drier for drying of red chilli (Capsicum annum L.)Solar Energy 85 (2011) 506–515

[4] Janjai S., Lamlert N., Intawee P., Mahayothee B., Bala, B.K., Nagle M.. Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. Solar Energy 83, (2009), 1550–1565

[5] J. Kaewkiew, S. Nabnean , S. Janjai .Experimental investigation of the performance of a large-scale greenhouse type solar dryer for drying chilli in Thailand, Procedia Engineering 32 (2012)433 – 439

[6] Kooli S., Fadhel A., Farhat A., Belghith A., 2007. Drying of red pepper in open sun and greenhouse conditions: Mathematical modelling and experimental validation. Journal of Food Engineering 55 (2007), 1094-1103

[7] Forson, F.K., Nazha, M.A.A., Rajakaruna, H.. Modelling and experimental studies on a mixed-mode natural convection solar cropdryer. Solar Energy 81 (2007), 346–357

[8] T.Y. Tunde-Akintunde Mathematical modeling of sun and solar drying of chilli pepper Renewable Energy 36 (2011) 2139e2145

[9] Dilip Jain, G.N. Tiwari, Modeling and optimal design of ground air collector for heating in controlled environment greenhouse, Energy Conversion and Management 44 (2003) 1357–1372

[10] Fadhel A., Kooli S., Farhat A., Belghith A. Experimental Study of the Drying of Hot Red Pepper in the Open Air, under Greenhouse and in a Solar Drier. International Journal of Renewable Energy & Biofuels Vol. 2014, Article ID 515285, 14 pages

[11] Inês N. Ramos, Teresa R.S. Brandão, Cristina L.M. Silva Simulation of solar drying of grapes using an integrated heat and mass transfer model**,** Renewable EnergyVolume 81, September 2015, Pages 896–902

[12] Karina Di Scalaa, Guillermo Crapisteb, Drying kinetics and quality changes during drying of red pepper LWT 41 (2008) 789–795

[13] Klein S.A., Beckman W.A. Duffie J.A., 1976. A design procedure for solar heating systems. Solar Energy 18, 113–127