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Indirect and Mixed Mode Solar Drying Mathematical Models for Sultana Grape

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ABSTRACT

Many research studies have been performed on forced convection (active) solar dryers for fruit and vegetables. A short survey of these showed that applying the forced convection solar dryer not only significantly reduced the drying time but also resulted in many improvements in the quality of the dried products. Active indirect and mixed-mode thin layer solar drying experiments were conducted on Sultana grapes. A combination of a solar air heater and a cabinet dryer was designed, constructed and tested for this product in the Agricultural Engineering Department at Shiraz University, Iran. Three air flow rates (0.085, 0.126 and 0.171 m^3 s^{-1}) and two types of drying systems (indirect and mixed-mode) were adopted. The south wall of the drying chamber was covered by a sheet of glass for mixed-mode and the glass sheet was covered with a thick sheet of cloth for an indirect solar drying system. Seven well-known thin layer drying models were used separately to fit the mixed-mode and indirect type experimental data for Sultana grapes. For experimental indirect data, the Modified Page model (r= 0.998, χ^2= 0.000241) and for experimental mixed-mode data, the Page model (r= 0.999, χ^2= 0.000169) showed the best curve fitting results with highest *r* (correlation coefficient) and lowest χ^2 (reduced chi-square) values. The constants in these models explain the effects of drying parameters, air velocity and temperature. To take account of these effects, the best correlation equations between the constants and drying parameters were also introduced using multiple regression analysis.

Key words: Cabinet solar dryer, Thin layer mathematical model.

INTRODUCTION

In any dried fruit production activity, the drying process may be the most important unit of operation. This method of preservation, if done correctly, can preserve and improve the quality and quantity of the end product effectively. Unsuitable preservation and storage methods cause losses ranging from 10 to 30% for cereals and 50 to 70% for fruits [16, 7 and 8]. Drying fruits allows for its preservation by reducing its water content and by inhibiting microbial growth and enzymatic modification. Some very important advantages of drying for most agricultural commodities include the reduction of their size and weight which facilitates transportation and reduces storage space and, more importantly, avoids the need for an expensive and sophisticated cooling system for maintaining their quality. Finally, it increases usage diversity allowing alternatives to the consumption of the products fresh and improving their shelf life, especially in rural areas [8 and 2].

Open sun drying is still the most common method used to preserve agricultural products in the majority of developing countries [23 and 8]. Although the method is cheap and simple but due to leaving the product unprotected from rain, windborne dirt and dust contamination, and infestation

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by insects, rodents, birds and other animals, the quality may be seriously degraded to such a degree that it sometimes become inedible [23 and 17]. Solar drying can be a feasible alternative for sun drying because it provides the most cost effective drying technique. In this technique the solar energy is used to heat up a stream of air which in turn flows through a bed of the commodity to be dried naturally or artificially. Since the material is contained there is less contamination and it is less susceptible to adverse weather conditions. A substantial amount of theoretical and experimental work has been reported on solar as well as open sun drying of vegetables and fruits [16, 15, 14, 10 and 12].

The natural convection (passive) solar drying system appears to have a good potential in many developing countries. This system is only suitable for a limited capacity and, owing due to low buoyancy induced airflow inside the dryer, the drying rate is very low and highly dependent on weather conditions which may reduce the quality of the drying products especially in adverse weather conditions [1 and 18].

Many research studies have been performed on forced convection (active) solar dryers for fruit and vegetables [14, 21, 22 and 10]. A short survey of these showed that applying the forced convection solar dryer not only significantly reduced the drying time but also resulted in many improvements in the quality of the dried products [18 and 21].

In forced convection solar dryers the drying material may be also exposed to direct solar radiation .This type of drying system in known as mixed-mode type while in an indirect type the drying process is only proceeded by hot air stream provided by a solar air heater.

For predicting the drying characteristics of the food stuffs in solar dryers, thin layer drying equations have generally been employed. These models were usually established on a theoretical, semi-empirical and empirical basis. Among these models, the theoretical approaches take into account only the internal characteristics of the product to moisture transfer while the semi-empirical and the empirical ones consider its external resistance to moisture removal between the air and the product [14, 3 and 20].

This study was mainly devoted to:

- Investigating thin layer solar drying for Sultana grapes using an active indirect and mixed-mode type solar dryer under different operating conditions.
- Choosing a suitable thin layer mathematical model for describing the indirect and mixed-mode solar drying processes.

MATERIALS AND METHODS

The rig consisted of a solar air heater, a reducer, a cabinet dryer, a blower with ducting system, a solar meter, temperature sensors, data acquisition system and a portable rig stand. This was erected outdoors in the Agricultural Engineering Department, of Shiraz University. The solar air heater and the dryer were tilted 45° towards the South, [4], Figure 1 (local latitude was 30°).

Solar Air Heater

Two single glazing air solar collectors were made from pressed wood 10 mm thick whose sides and back walls were thoroughly covered by glass wool (50 mm in thick). For each solar air heater a sheet of glass (4 mm in thick, with 1 m wide and 2 m long was used as a transparent cover. Two sheets of aluminum (1.5 mm thick 1×2 m^2) painted matt black were used as absorber plates. These two collectors were tightly fixed together side-by-side to make a rigid single module solar air heater with an effective surface area of 4 m^2 with a depth of 100 mm.

In order to connect the solar air heater to the cabinet dryer, a reducer 100 mm in width and 2,000 mm in length at the larger end and

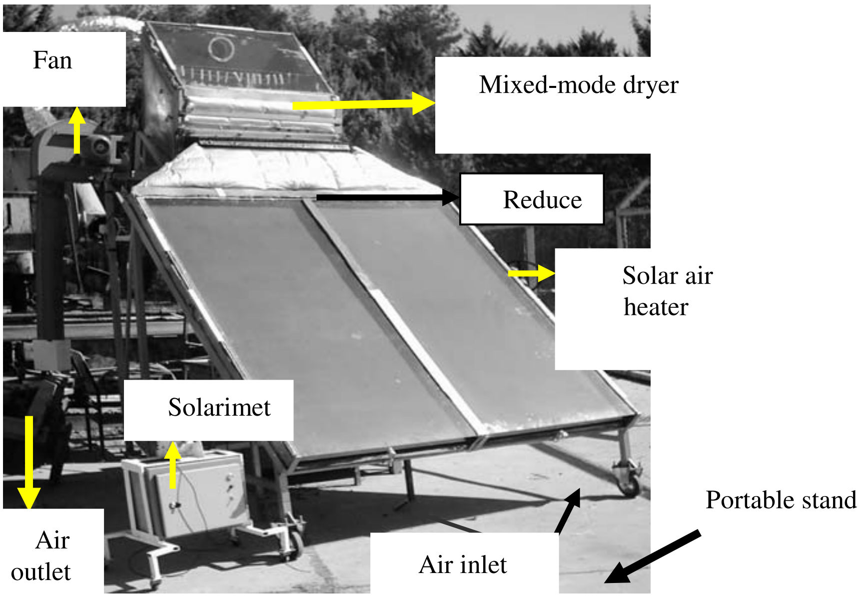

Figure 1. Sultana grapes solar dryer in mixed-mode condition type with solarimeter.

200 mm in width, 1,000 mm in length at the smaller end was used. The reducer was made of pressed wood and was well insulated by glass wool.

Solar Cabinet Dryer

The drying cabinet was constructed from 1 cm pressed wood, and fully insulated by glass wool on its sides, back and bottom walls. The slanted front wall (with 45° inclination) was covered by a 4 mm thick glass sheet, to let the sun light to pass through and hit the drying products (mixed-mode). This transparent wall may be covered with an opaque and insulated sheet for indirect mode of dryer application. On the back wall (north side) a lid was incorporated to give operator access for loading and unloading the dryer. On the uppermost part of the back side wall of the dryer an exhaust hole 150 mm in diameter` was made through which humid air can be sucked out by the fan. On the lowest part of the front wall a rectangular opening 200 mm in height and 1,000 mm in length was made to let the hot air from the solar collector reducer to enter the dryer plenum chamber. In order to have uniform air distribution in the dryer, the bottom of the plenum was tilted from front to rear of the plenum for reducing the cross section area of the plenum gradually. The dimensions of the cabinet dryer were: 1,000 mm in length, 500 mm in width, 500 mm front height and 850 mm rear height. The drying trays were made of a wooden frame on all four sides with plastic netting (1.5×1.5 mm) on the bottom to hold the samples. To conduct the experiments, two trays of the same length but a different width were used in the dryer. The lower tray was 960 mm in long and 460 mm wide, and the upper one was 260 mm wide (the total tray surface area was 0.691 m^2). The distance between the trays was set in such away that the upper tray did not cast any shadows on the lower one during the mixed-mode drying experiments.

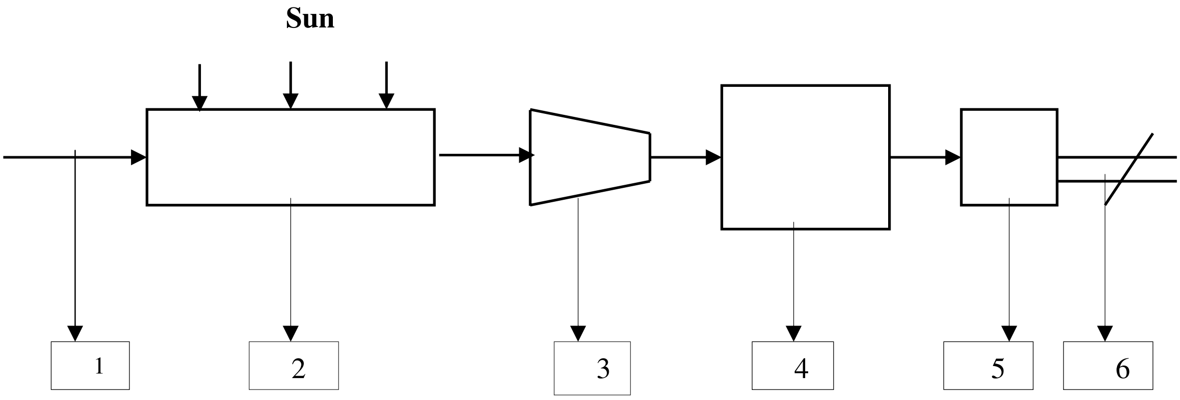

Figure 2. Flow diagram of the solar drying system 1-ambient air inlet, 2-solar air heater, 3-reducer, 4-indirect and mixed mode solar cabinet dryer containing two shelves, 5-fan and, 6-exit air and air flow rate adjusting tool (damper).

Instrumentations

A centrifugal fan (1400 RPM and 750 W) was installed on the downstream for sucking the ambient air through the solar air heater and then the cabinet dryer. To conduct the experiments at different air flow rates, an adjustable butterfly damper was incorporated into the fan exhaust pipe (Figures 1 and 2). A long circular duct (150 mm in diameter and 1,500 mm in long) was connected to the fan exhaust. At the end of this duct an accurate photoelectric type air velocity meter (Intelligent meter, YK-2001AL, ±0.1 m s^{-1}) and dry and wet bulb thermometers (±0.5°C) were inserted. Air temperatures were recorded and monitored at different positions of the drying system by means of ten SMT 160 temperature sensors (±0.5°C; three at the solar air heater inlet, three at the dryer plenum chamber, three at the air exit from the dyer cabinet and one at the fan air exit just near the damper) at regular intervals of 5 minutes via a data acquisition system. The tips of the sensors were fully covered with aluminum foil to reduce radiation errors. The solar intensity was measured and recorded at the same time interval using a Casella Pyranometer (0-2000 W m^{-2}, 1 mv= 1W m^{-2}) placed beside the plane of the collector at the same inclination angle (Figure 1).

Experiments

Two series of drying experiments were carried out during September and October 2005 at the College of Agriculture, Shiraz University (Iran). The first set was devoted to indirect type and the next set of experiment was conducted on mixed-mode type dryer. Three replications were made for each set at a given air flow rate. In order to investigate the effect of air flow rate on the thin layer solar drying parameters for each set, three ranges of air flow rates of 0.171, 0.126 and 0.085 m^3 s^{-1} (air velocities of 9.3–4.7 m s^{-1}) were adopted. For each drying period, the dryer was started at 10 a.m. and the drying process continued until 4 p.m. each day. During each trial, the initial and interval weight measuring of the grapes on the trays were performed using an electronic balance (Sartorium, model: 2354, 1 kg±0.01 g) by picking up the samples hourly from the trays. Each sampling required about 20 seconds to be completed. The moisture contents of the grape samples were measured at the start and end of each interval by drying the samples in an air ventilated oven at 105°C for 24 hours [7 and

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Table 1. Proposed mathematical models for Sultana grapes thin layer drying.

Model	**Equation**
Newton (1)	$MR= Exp(-kt)$
Page (2)	$MR= Exp(-kt^n)$
Modified Page (3)	$MR= Exp(-(kt)^n)$
Henderson and Pabis (4)	$MR= a\ exp(-kt)$
Logarithmic (5)	$MR= a\ exp(-kt)+c$
Two- term (6)	$MR= a\ exp(k_0t)+ b\ exp(-k_1t)$
Wang and Singh (7)	$MR= 1+ at + bt^2$

Where: *k, n, a, b, c,* k_0 and k_1 are constants and *t* is the drying time.

2]. At the highest air flow rate, 0.171 $m^3\ s^{-1}$, the drying air temperature varied from 37 to 42°C, at the medium air flow rate of 0.126 $m^3\ s^{-1}$, from 42 to 47°C and at the lowest air flow rate of 0.085 $m^3\ s^{-1}$, from 48 to 53°C. During the course of the experiments the average ambient air temperature was 20°C, the average outside air relative humidity was 25% and the average solar insolation was 850 W m^{-2}.

The grapes were harvested manually (average initial moisture content of 78% w.b.) and checked carefully for any infections. In general, the use of pretreatment solutions removes the waxy layer, induces micro pore formation on the cuticle, increases drying rate of grapes, reduces drying time and improves the quality of final products. In this study the grapes were pretreated with 5% K_2CO_3+2.5% vegetable oil solution. Dipping time for pretreatment with the solution was about 5 seconds and maximum solution temperature was about 90°C [11]. The grapes were then pretreated with SO_2 gas [11]. The prepared samples were spread evenly and tightly in thin layers on drying trays with a packing density of 15 kg m^{-2} and placed on the shelves of the drying cabinet. The average final moisture content of the product was 15% w.b.

Thin Layer Drying Mathematical Models

Although the moisture ratio (MR) was defined as $MR= (M_i-M_e)/(M_o-M_e)$ [21] but, due to continuous fluctuations in drying air relative humidity in the solar dryers, the

Table 2. Thin layer modeling for indirect type solar drying and pertinent constants.

Model	r	χ^2
Newton k= 0.1221	0.964	0.011701
Page k= 0.4088, n= 0.6152	0.998	0.000254
Modified Page k= 0.2271, n= 0.6305	0.998	0.000241
Henderson and Pabis k= 0.0808, a= 0.4203	0.932	0.040211
Logarithmic k= -0.0471, a= -0.0985, c= 0.363	0.669	0.077505
Two-term k_0= 8.3030, a= 0.0109, b= 0.3109, k_1= 0.0021	0.930	0.012102
Wang and Singh a= 0.0278, b= 0.00021	0.942	0.016602

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Table 3. Thin layer modeling for mixed mode type solar drying and pertinent constants.

Model	r	χ^2
Newton *k*= 0.1362	0.942	0.017903
Page *k*= 0.5921, *n*= 05118	0.999	0.000169
Modified Page *k*= 0.3481, *n*= 0.5207	0.999	0.000247
Henderson and Pabis *k*= 0.0795, *a*= 0.3481	0.881	0.056105
Logarithmic *k*= -0.0442, *a*= -0.0911, *c*= 0.2993	0.649	0.099511
Two-term K_0= 5.3301, *a*= 0.2235, *b*= 0.5711, k_1= 0.1223	0.982	0.000228
Wang and Singh *a*= 0.0314, *b*= 0.00025	0.910	0.017507

moisture ratio was simplified to $MR= M_t/M_o$ [22 and 3]. In order to investigate the thin layer drying properties of biological materials, several well-known mathematical models have been applied among which the following models (Table 1) were extensively reported to be suitable for high moisture content products [6, 2 and 14].

Where: *k, n, a, b, c,* k_0 and k_1 are constants and *t* is the drying time.

The thin layer solar drying data were fitted to the above models to find the best fit model for the indirect and mixed-mode type solar drying processes separately. To validate the goodness of the fittings two criteria, namely the correlation coefficient, *r* and mean square of deviations between the experimental and calculated values for the models, χ^2 (chi square) were employed. Higher *r* values with lower, χ^2 values indicate a better curve fitting [23, 22 and 20].

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N-P} \quad (8)$$

$$r = \frac{\sum_{i=1}^{N}(MR_{\exp,i} - \overline{MR}_{\exp})(MR_{pre,i} - \overline{MR}_{pre})}{\sqrt{\sum_{i=1}^{N}(MR_{\exp,i} - \overline{MR}_{\exp})^2 \sum (MR_{pre,i} - \overline{MR}_{pre})^2}} \quad (9)$$

Where, $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ the ith predicted moisture ratio, *N* the number of the

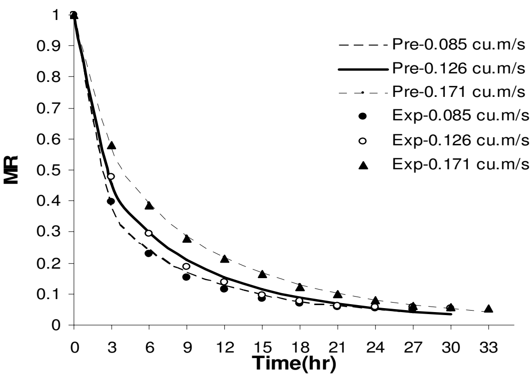

Figure 3. Comparing predicted and experimental MR values versus drying time at three air flows for an indirect type solar drying system.

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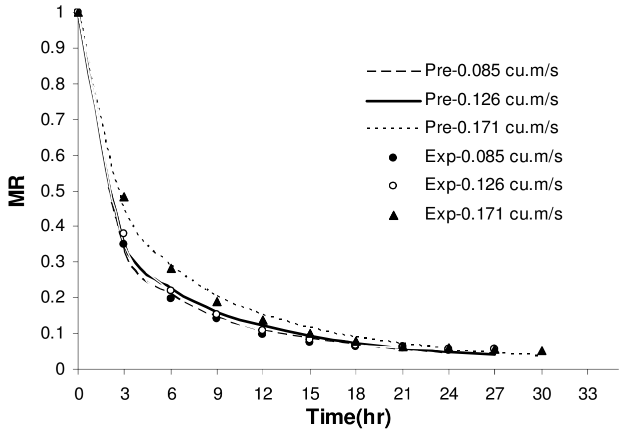

Figure 4. Comparing predicted and experimental MR values versus drying time at three air flows for mixed-mode type solar drying system**.**

observations and P the number of constants in the equations, $\overline{MR}_{\exp}$ is the average of sum of the $MR_{\exp,i}$ and $\overline{MR}_{pre}$ is average of sum of the $MR_{pre,i}$. EXCEL and MAT LAB software were employed to analyze the data.

RESULTS AND DISCUSSION

For the two different solar drying types, indirect and mixed-mode, the moisture ratio values of the samples were calculated at different drying air flow rates and drying air temperatures during the drying processes. These MR values were then fitted separately against the drying time. The Modified Page model showed the best curve fitting results (highest r and lowest χ^2 values; Table 2) for the indirect type and the Page model for mixed-mode type (Table 3). The Modified Page model was therefore selected to present the thin layer indirect solar drying and the Page model for presenting the thin layer mixed-mode type solar drying at different drying air flow rates and drying air temperatures for Sultana grapes.

There are two constants in each selected

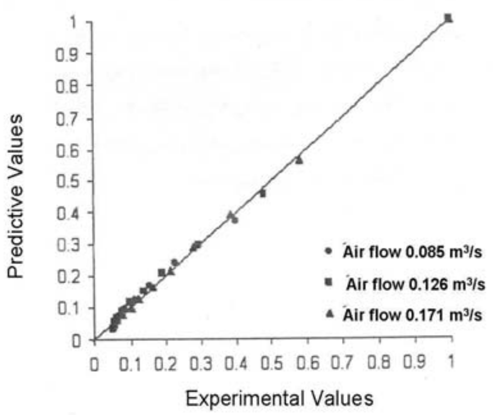

Figure 5. Experimental vs. predicted moisture ratio (MR) values for indirect solar drying process.

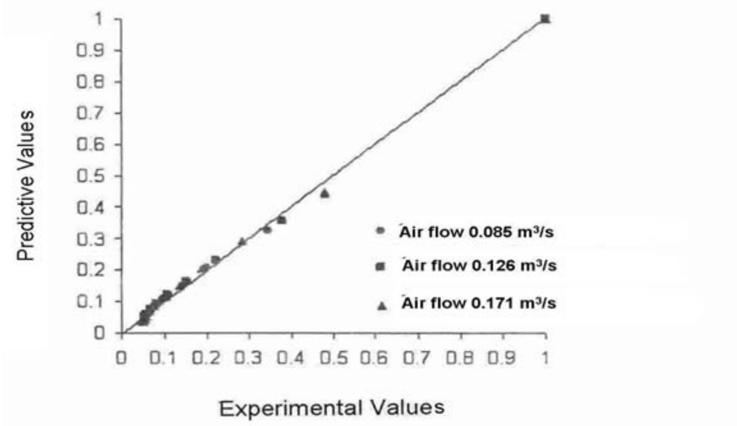

Figure 6. Experimental vs. predicted MR values for mixed solar drying process.

model related to the effects of drying air temperatures and air flow rates (air velocities). In order to formulate the relationship between the constants and drying parameters (drying air temperatures and velocities), the multiple regression analysis method was employed for all data in each type of solar drying.

In Modified Page model (indirect) the correlations for constants, taking into account the drying parameters, drying air temperature and velocity, were:

k= 0.48370-0.0361V+0.000074T R^2= 0.989

n= 0.37588+0.036222V-0.00002T R^2= 0.994

In Page model (mixed) the correlations for constants were:

k= 1.14003-0.06099V-0.00333T R^2= 0.983

n= 0.2038+0.03227V+0.00226T R^2=0.931

Where, V= Air velocity, m s^{-1},

T= Drying air temperature, ° C.

Using the proper model with known drying air velocity and temperature, the moisture ratio and the moisture content values can be estimated at any drying time for indirect and mixed-mode type solar dryers.

The experimental and predicted moisture ratio values (MR) versus drying time at three air flow rates and two different drying systems were shown in Figures 2 and 3.

The moisture ratio decreases with a diminishing rate at different air flow rates and for two solar drying systems. This means that all drying periods were performed in the falling rate period. These results are in good agreement with the results of other researchers who had some extensive research on the solar drying of different products such as pistachio, chilli, crapes etc. [23, 22, 13 and 9]. The steepest slope belonged to air the flow rate of 0.085 m^3 s^{-1} and mixed mode type because, in this process, the drying air temperature was high due to slow air velocity in the air solar collector and the product was also exposed to direct solar radiation. This means that the moisture removal was high not only due to the warmer drying air which resulted in a higher magnitude of the moisture diffusion coefficient but was also due to a radiation beam which resulted in a higher temperature and evaporation rate on the product surface.

time was 5.5 days at 0.171 m^3 s^{-1} for the indirect type.

CONCLUSIONS

In order to find the best mathematical model for Sultana grapes thin layer solar

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drying of the indirect and mixed-mode type, a cabinet solar dryer was employed. The Modified Page and Page models showed the best curve fitting results for the experimental moisture ratio (MR) values for indirect and mixed-mode type, respectively. The drying parameter effects, namely air velocity and temperature, were established by introducing the best fit correlation equations for the constants involved in the selected mathematical model.

Nomenclature

a, b, c Constants
k, k_1, k_0, n Constants
M_i Moisture content at time t, % d.b.
M_0 Initial moisture content,, % d.b.
M_e Equilibrium moisture content,, % d.b.
MR Moisture ratio
$MR_{exp,i}$ Experimental moisture ratio
MR_{prei} Predicted moisture ratio
N Number of observations
P Number of constants in the equations
r Correlation coefficient
V Drying air velocity, m s^{-1}
T Drying air temperature, ° C
t Time, (min.+h.)
χ^2 Reduced chi square

REFERENCES

1. Bala, B. K. and Woods, J. L. 1994. Simulation of the Indirect Convection Solar Drying of Rough Rice. *Solar Energy*, **53**: 259-266.
2. Brooker, D. B., Baker-Arkema, F. W. and Hall, C.W. 1991. *Drying and Storage of Oilseeds*. New York.
3. Diamante, L. M. and Munro, P. A. 1991. Mathematical Models Hot Air Drying of Sweet Potato Slice. *Int. J. Food Sci. Technol.*, **26**: 99-106.
4. Duffie, J. A. and Beckman, W. A. 1991. *Solar Engineering of Thermal Processes 2nd Ed.*. New York, 1991.
5. Forson, F. K., Nazha, M. A. A. and Rajakaruna, H. 2007. Modeling and Experimental Studies on Mixed-Mode Natural Conversion Solar Crop Dryer. *Solar Energy*, **81**: 346-357.
6. Hall, C. W. 1980. Drying and Storage of Agricultural Crops. Westport.
7. Henderson, S. M. and Perry, R. L. 1976. *Agricultural Process Engineering*. New York.
8. Hossain, M. A. and Bala, B. K. 2007. Drying of Hot Chilli Using Solar Tunnel Dryer. *Solar Energy*, **81**: 85-92.
9. Lahnsasni, S., Kouhila, M., Mahrouz, M. and Jaouhari, J. T. 2004. Drying Kinetics of Prickly Pear Fruit (*Opuntia ficus* Indica). *J. Food Eng.*, **61**: 173-179.
10. Lutz, K. and Muhlbauer, W. 1989. Solar Tunnel Dryer with Integrated Collector. *Dry. Technol.,* **4**: 583-590.
11. Mahumutoglu, T., Emir, F. and Saygi, Y. B. 1996. Sun/solar Drying of Differently Treated Grapes and Storage Stability of Dried Grapes. *J. Food Eng*., **29**: 289-300.
12. Mangaraj, S., Singh, A., Samuel, D. V. K.; and Singhal, O. P. 2001. Comparative Performance Evaluation of Different Drying Methods for Chillies. *J. Food Sci. Technol.*, **38**: 296-299.
13. Midilli, A. and Kucuk, H. 2003. Mathematical Modeling of Thin Layer of Pistachio by Using Solar Energy. *Energy Conv. Manage.*, **44**: 1111-1122.
14. Maskan, A., Kaya, S. and Maskan, M. 2002. Hot Air and Sun Drying of Grape Leather. *J. Food Eng*., **54**: 81-88.
15. Phoungchandang, S. and Woods, J. L. 2000. Solar Drying of Banana: Mathematical Model, Laboratory Simulation and Field Data Compare. *J. Food Sci.,* **65**: 990-996.
16. Ratti, C. and Mujumdar, A. S. 1997. Solar Drying of Foods: Modeling and Numerical Simulation. *Solar Energy*, **60**: 151-157.
17. Sacilik, K., Keskin, R. and Elicin, A. 2006. Mathematical Modeling of Solar Tunnel Drying of Thin Layer Organic Tomato. *J. Food Eng.,* 2006, **73**: 231-238.

[DOR: 20.1001.1.16807073.2009.11.4.9.4]

18. Schirmer, P., Janjai, S., Esper, A., Smitabhindu, R. and Muhlbauer, W. 1996. Experimental Investigation of the Performance of the Solar Dryer for Drying Banana, *Renew. Energy*, **7**: 119-129.
19. Tiris, C., Tesia, M. and Dincer, I. 1996. Experiments on a New Small Scale Solar Dryer. *Appl. Thermal Eng.,* **16**: 183-187.
20. Togrul, I. L. and Pehlivan, D. 2002. Mathematical Modeling of Apricots in Thin Layer. *J. Food Eng.,* 2002, **55**: 209-216.
21. Trim, D. S. 1982. Development of a Forced Convection Solar Dryer for Red Chilli. *Tropical Agri*. (Trinidad), **59**: 319-323.
22. Yaldiz, O., Ertekin, C. and Uzun, H. I. 2001. Mathematical Modeling of Thin Layer Solar Drying of Sultana Grapes. *J. of Energy*, 42: 167-171.
23. Yaldiz, O. and Ertekin, C. 2001. Thin Layer Solar Drying of Some Vegetable. *Dry.Technol.,* **19**: 583-597.

مدلهای ریاضی خشک کردن خورشیدی به روش مختلط و غیر مستقیم برای انگور سلطانی

ع. زمردیان و م. داداش زاده

چکیده

تحقیقات دامنه داری توسط محققین مختلف درکاربرد خشک کن های فعال خورشیدی برای میوه جات و سبزیجات صورت گرفته است . با یک نظر اجمالی به تحقیقات انجام شده به این مهم دست خواهیم یافت که با بکارگیری این خشک کن ها نه تنها زمان خشک شدن بنحو چشم گیری کاهش می یابد بلکه محصول خشک شده از کیفیت خوبی برخودار خواهد بود. آزمایشاتی برروی یک خشک کن خورشیدی بطریقه مختلط و غیر مستقیم برای محصول انگور در بخش مهندسی مکانیک ماشینهای کشاورزی دانشگاه شیراز انجام شده است. خشک کن مزبور از یک کالکتور تحت خورشیدی و یک مخزن خشک کن قفسه ای تشکیل یافته که در سه دبی (۰/۰۸۵، ۰/۱۲۶و ۰/۱۷۱ مترمکعب در ثانیه) مورد آزمایش قرار گرفته است .برای تبدیل خشک کن ازحالت مختلط به حالت غیر مستقیم کافی است دیواره شیشه ای جنوبی بدنه خشک کن را با یک پارچه ضخیم بپوشانیم. برای بررسی روند خشک کردن انگور ۷ مدل ریاضی مطرح مورد ارزیابی دقیق قرار گرفت . برای خشک کردن خورشیدی برروش مختلط بهترین مدل با درنظر گرفتن کمترین مقدار χ^2=۰/۰۰۰۱۶۹ و بیشتر مقدار R=۰/۹۹۹ مدل پیچ و برای روش غیر مستقیم به دلائل فوق (χ^2 = ۰/۰۰۰۲۴۱ و R= ۰/۹۹۸) مدل تصحیح شده پیچ مورد پذیرش قرارگرفت. برای بررسی بیشتر ایندو مدل و اینکه ثوابت موجود در مدلها چه رابطه ای با شرایط حاکم بر خشک شدن دارند، با استفاده از رگرسیون چند متغیره روابط معقولی بین ثوابت موجود در مدلها درجه حرارت و سرعت هوای خشک کننده بیان گردیدند.

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