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Drying of Orange Slices in CHP Dryer

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ABSTRACT

In this research, the effect of variations in engine power (drying temperature), different thickness of orange slices at constant air flow, effective moisture diffusivity and activation energy using a laboratory combined heat and power (CHP) dryer were investigated. The drying of orange thin layer slices in CHP dryer with three thicknesses of 3, 5 and 7 mm, four levels of load on the engine (25, 50, 75 and 100%) in order to generate temperatures of 50, 65, and 80 °C 95 at constant air flow rate of 1 m/s is carried out. Drying curves based on the data obtained from the experiments were fitted with different mathematical models. The model of Midilli et al. based on three parameters value of R^2, χ^2 and RMSE is fitted better than others for drying kinetics curve of orange thin layer slices.

Key words:

Introduction

Citrus has been planted in many region of the world where tropical and subtropical climates have. For this reason, different varieties of citrus fruits are called as subtropical which can commonly be at temperature between 0 to 40 °C. Today, the drying of fruit slices like orange, apple, kiwifruit, banana and etc is developed in worldwide and have been sold in the market at high prices. Drying is one of the oldest methods of food and crop preserving for a long period [8]. Appropriate methods of drying, reduce losses and damage during storage and help to improve product quality. Using this method, in addition to preventing food spoilage by microorganisms or chemical reactions, the weight of food decreases and caused to save the transportation costs [25]. It needs long time and high temperature for reduce the food moisture till it be a long period of storage capability (especially for fruits). During drying some undesired changes have been happened such as changes in color, taste, smell, nutrition decrement, increment in special weight (due to shrinkage) and decrement in rehydration capacity [17,22]. Drying is the process of removing moisture using heat transfer which its correct operation, is so important due to potential of unfavorable changes in the diet. In this study the drying operations of agricultural products are done using of the CHP dryer which it in return uses of output heat of the engine (engine waste heat). A CHP system has some advantage such as: increasing the energy efficiency, decreasing costs of primary energy for consumer, supplying of electric energy with much higher quality [12,37,38].

Some researchers have carried out in drying of agriculture products with waste heat from engine such as: [1,5,6,7], biomass drying [23,31], pulp and paper mill [18], clay minerals [16] grand composite [21].

For safe storage of food and agricultural products is necessary to get them to a certain moisture level. To achieve this goal should be modeled the drying of agricultural products [33]. Mathematical models are able to predict the drying of products and also kinetics of moisture diffusion has been applied for granular and layer materials or thin layer drying of agricultural products [9,30]. One of the effective methods for designing and optimizing dryers is the predicting and modeling the process of drying. The most important part of the drying process is the predicting of drying time and drying rate. Common methods of drying curve analysis for agricultural products and foods in processing cycle are based on solving the heat and mass transfer equations and using statistical methods or regression equations. Since the prediction of quantitative and qualitative indicators includes some input and output variables, it is difficult to analyze mathematically. The accuracy of mathematical models and statistical methods has been predicted with three parameters of R^2, χ^2 and RMSE.

Also some research have carried out in drying of agriculture products such as: mint leaves [13],

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pomegranate arils [26,27], Sweet cherry [14], Mushroom slice [26,35] carrot cubes [39,29,2], wheat [32], herbal leaves, *Gundelia tournefortii* L. [15], apple slice [36,40], eggplant [4], longan [10], tomato [34], yellow pea [24], red pepper [3].

However, there is no extensive and complete research on the drying of agricultural products using the exhaust's hot leaving gas in different engine loads and, therefore, in different drying temperatures. The objectives of this study are:

1- Investigating the drying of orange slice inside a CHP dryer;

2- Determining the mathematical models during the drying process of orange slice.

Material and Methods

2.1. Materials:

In this study, orange slice were used to conduct the experiments. The study samples were freshly provided. Orange slice were placed on the drying bed after preparing and setting the CHP dryer for different experimental levels. A motor and a generator with the following specification were used.

Engine Type: single cylinder- 4-stroke Air-cooled, power: 6.5 hp @ 1200 rpm, Displacement: 196 CC, Bore x Stroke: 68×54 mm, Fuel Types: Natural gas (N), LPG (L), Ignition system: Transistor Coil Ignition (T.C.I).

Generator Type: Single-Phase AC Synchronous, Frequency: 50 HZ, Current (A) / DC voltage (V): 12V/8A, Maximum power: 2.3 kW, Power rating: 2 kW.

Air parameters were adjusted by measuring temperature and velocity using thermometer (Lutron, TM-925, Taiwan) and anemometer (Anemometer, Lutron-YK, 80AM, Taiwan).

The drying process continued until the weight of samples became fixed. During the drying experiments, the variation range of ambient temperature was 23±3°C and of ambient relative humidity was 24±4 percent. The AOAC standard (1980) was employed to measure the initial moisture content (MC) of apple slice. The initial MC of orange slice was 85.4% (w.b.).

2.2 System Description:

In this work from exhaust waste heat of an engine-generator was used for drying process. Equipment used in this dryer consist of a single cylinder engine that works with natural gas fuel, a generator that produces 2 kW of electricity, gas flow meter for measuring fuel consumption, a dryer chamber which samples place in it, a fan to remove hot air of the dryer chamber, a digital balance for weighing samples, temperature sensor for measuring temperature and a PC to record hot air temperature and sample weight. Schematic diagram of this dryer is shown in Fig.1.

Waste heat from the engine exhaust was directed into the dryer chamber. The heat is approached directly under the chamber page and the drier's chamber is warmed. Hot air is circulated inside the chamber and is removed from the chamber by a fan. Engine was run for a few minutes to reach steady state conditions. The drying experiments were performed at constant speed and four load levels, 25%, 50%, 75% and full load (100%). About 50g samples with a thickness of 3, 5 and 7 mm were placed dryer chamber and were dried. Samples were weighted automatically by the digital balance with ±0.01 accuracy for 5 min.

2.3. Mathematical Modeling:

Twelve moisture ratio models were fitted to the experimental drying data (Table1). These models are typically derived by simplifying the general series solutions of Fick's second law and considering a direct relationship between the average water content and drying time [13].

The moisture ratio (MR) of orange slice during the drying experiments was calculated by using equation (1):

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where, MR is the moisture ratio (dimensionless), M_t is the moisture content at any given time (kg water/kg solids), M_e is equilibrium moisture content (kg water/kg solids) and M_0 is the initial moisture content. As M_e is much lower than M_0 and M_t, it is negligible [25], then the equation could be simplified as follows:

$$MR = \frac{M_t}{M_0} \tag{2}$$

Three different criteria were used for evaluation of the fit: correlation coefficient, R^2; chi-squared, χ^2, and Root Mean Square Error, *RMSE*. The most suitable model for describing drying characteristics of cherries would be a model with the highest R^2 and the lowest χ^2 and RMSE values.

$$R^2 = \frac{\sum_{i=1}^{N}(MR_{\exp,i} - \overline{MR}_{\exp})(MR_{pre,i} - \overline{MR}_{pre})}{\sqrt{\sum_{i=1}^{N}(MR_{\exp,i} - \overline{MR}_{\exp})^2 \sum (MR_{pre,i} - \overline{MR}_{pre})^2}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp,i} - MR_{pre,i})^2}{N - m} \tag{4}$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2\right)^{\frac{1}{2}} \tag{5}$$

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$MR_{exp,i}$ is the i_{th} moisture ratio value determined experimentally, $MR_{pre,i}$ is the i_{th} predicted moisture ratio value, N denotes the number of observations and m is the number of drying constants. The drying rate of orange slice was calculated using the following equation. (6) [3].

$$\text{Drying Rate} = \frac{M_{t+dt} - M_t}{dt} \quad (6)$$

Where, (M_{t+dt}) is moisture content at time ($t+dt$) (kg water/kg dry matter), M_t is moisture content at time t (kg water/kg dry matter) and t is drying time (min).

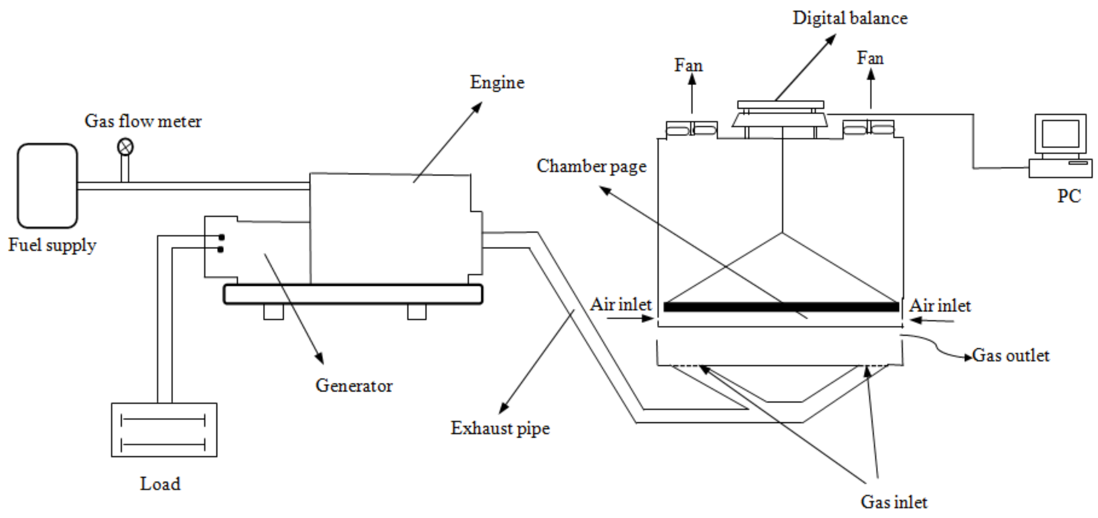

Fig. 1: Schematic diagram of the CHP dryer.

Table 1: Standard models reported in the literature used for drying of agricultural products.

Model	Mathematical Function	Ref.
Wang and Singh	$MR = at^2 + bt + c$	(Motevali *et al.*, 2010)
Henderson and Pabis	$MR = a\exp(-kt)$	(Chhinnan, 1984)
Logaritmic	$MR = a\exp(-kt) + c$	(Dandamrongrak *et al.*, 2002)
Modified Page	$MR = \exp(-(kt)^n)$	(Wang *et al.*, 2007))
Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	(Ertekin and Yaldiz, 2004)
Page	$MR = \exp(-kt^n)$	(Motevali *et al.*, 2010)
Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(Sharma *et al.*, 2005)
Newton	$MR = \exp(-kt)$	(Motevali *et al.*, 2010)
Midilli *et al.*	$MR = a\exp(-kt^n) + bt$	(Motevali *et al.*, 2010)

Results and Discussion

Study the figures 2 Shows that drying time of orange layers decreases by increases of the load on the engine and increasing the outlet temperature of the exhaust which in return caused the increment in drying temperature. The reason is that by increasing temperature the molecular movement of water or its steam into the product increases and caused rapid flows. Also, by increasing temperature, the equilibrium moisture content of the product surface by drying air decreases and so caused more decrement in moisture of product surface. Besides, when the moisture of product surface more decreased, the moisture gradient between the surface and center of the product increases, the flow of moisture becomes more rapid through the product and caused to increase the output moisture, so the drying time decreases. Figure 2 shows that by increasing temperature to 80 and 95 °C (75- 100 % load) the moisture of orange slices goes rapidly and the drying time has significant difference than two other temperatures of 50 and 60 °C (25- 50 % load). The heating of orange slices to reach evaporation temperature is occurred through the conduction. Since the drying of orange slices is carried out using CHP method and heat conduction of this method is low so the drying time is done as long. On the other hand, at high temperatures (80 and 95 °C) a hard layer beneath outer layer of orange slices is formed due to existence of sugar components in orange and drying of product outer layer. This hardened layer creates a barrier against moisture diffusion at product surface and caused a long drying time. The results of drying orange slices showed that the minimum and maximum drying time obtained at full engine load (temperature of 95 °C), thickness of 3 mm as 95 minutes and at engine load of 25% (temperature of

50 °C), thickness of 7 mm as 300 minutes, respectively.

Moisture ratio of various experimental data in the CHP dryer obtained using the relation 1. Experimental data were fitted with experimental models (Table 1) and based on three parameters value of R2, χ^2 and RMSE, the Midilli *et al*. model was selected as best mathematical model. The results of fitted experimental models on the experimental data are shown in (Table 2 3, 4 and 5). The results of fitting the Midilli *et al*. model on the experimental data showed that by increasing the load on the engine and drying temperature the constant drying rate (k) increases. Also, by decrement in sample thickness from 7 to 3 mm the constant drying rate is increased.

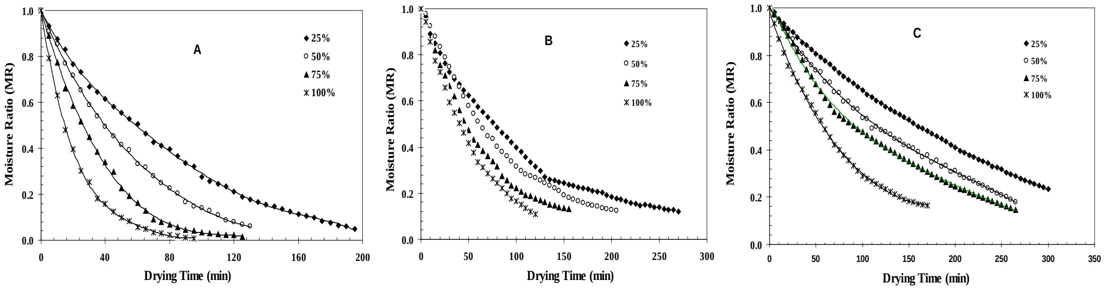

Fig. 2: Thin-layer drying curves of orange slice in different thickness (A) 3, (B) 5 (C) 7 mm.

Table 2: Regression coefficients and standard deviations of thin layer drying models for CHP at 25% load.

25%									
model	3 mm			5 mm			7 mm		
	R^2	X^2	RMSE	R^2	X^2	RMSE	R^2	X^2	RMSE
Newton	0.9955	2.6128E-04	0.01640	0.996	2.4966E-04	0.0158	0.9968	1.5628E-04	0.0125
page	0.9965	2.6385E-04	0.01646	0.9983	1.0412E-04	0.01029	0.9988	6.0900E-05	0.007869
Modified Page	0.9965	2.6385E-04	0.01646	0.9983	1.0412E-04	0.01029	0.9988	6.0900E-05	0.007869
Wang and Singh	0.9934	4.9077E-04	0.02244	0.9896	6.4559E-04	0.02563	0.9991	4.4967E-05	0.006762
Modified Henderson and Pabis	0.995	3.7051E-04	0.0195	0.9968	1.9254E-04	0.014	0.9974	1.2975E-04	0.01149
Logaritmic	0.995	3.7051E-04	0.0195	0.9994	3.9051E-05	0.006358	0.9974	1.2975E-04	0.01149
Approximation of diffusion	0.993	5.2128E-04	0.02344	0.9994	3.4542E-05	0.005979	0.9968	1.5628E-04	0.01271
Modified Page 2	0.991	2.6385E-04	0.01668	0.9983	1.0412E-04	0.01038	0.9988	6.0900E-05	0.007939
Midili *et al*.	0.999	1.6462E-04	0.02392	0.9995	3.3610E-05	0.005944	0.9992	1.0703E-04	0.002392

Table 3: Regression coefficients and standard deviations of thin layer drying models for CHP at 50% load.

50%									
model	3 mm			5 mm			7 mm		
	R^2	X^2	RMSE	R^2	X^2	RMSE	R^2	X^2	RMSE
Newton	0.9948	4.1808E-04	0.02045	0.9935	4.3756E-04	0.02092	0.9984	8.9604E-05	0.009466
page	0.9982	1.4250E-04	0.01217	0.9936	5.1463E-04	0.01781	0.9984	8.9396E-05	0.009546
Modified Page	0.9982	1.4250E-04	0.01217	0.9936	5.1463E-04	0.01781	0.9984	8.9396E-05	0.009546
Wang and Singh	0.9966	2.6965E-04	0.01675	0.9964	2.4512E-04	0.01585	0.9956	0.00024189	0.0157
Modified Henderson and Pabis	0.9957	3.4131E-04	0.01884	0.9939	4.0805E-04	0.02045	0.9984	8.9604E-05	0.009557
Logaritmic	0.9994	4.8577E-05	0.007256	0.9978	1.4851E-04	0.0125	0.9984	8.2377E-05	0.009253
Approximation of diffusion	0.9948	8.1846E-04	0.01087	0.9953	3.1732E-04	0.01836	0.9984	8.9698E-05	0.009655
Modified Page 2	0.9594	3.2504E-03	0.05934	0.9936	5.2122E-04	0.01781	0.9981	0.00010445	0.01042
Midili *et al*.	0.0999	4.9808E-05	0.007513	0.9996	2.3683E-05	0.005072	0.9985	8.2377E-05	0.009253

Table 4: Regression coefficients and standard deviations of thin layer drying models for CHP at 75% load.

75%									
model	3 mm			5 mm			7 mm		
	R^2	X^2	RMSE	R^2	X^2	RMSE	R^2	X^2	RMSE
Newton	0.9936	5.6120E-04	0.02369	0.9992	5.4800E-05	0.007402	0.9952	2.6896E-04	0.0164
page	0.9982	1.5800E-04	0.01283	0.9994	3.8400E-05	0.006303	0.9964	1.9815E-04	0.01423
Modified Page	0.9982	1.5800E-04	0.01283	0.9994	3.8400E-05	0.006303	0.9964	1.9815E-04	0.01423
Wang and Singh	0.9895	9.2200E-04	0.03099	0.9957	2.8353E-04	0.01713	0.009511	4.7729E-04	0.02208
Modified Henderson and Pabis	0.995	4.4200E-04	0.02146	0.9992	5.2533E-05	0.007372	0.9953	2.6208E-04	0.01636
Logaritmic	0.9975	2.1700E-04	0.01536	0.9988	1.5060E-05	0.004017	0.9971	1.6323E-04	0.01305
Approximation of diffusion	0.9936	5.6120E-04	0.0247	00.9988	1.4093E-05	0.003886	0.997	1.6769E-04	0.01323
Modified Page 2	0.7306	6.4080E-03	0.5904	0.9984	2.1380E-04	0.001152	0.9964	1.9817E-04	0.01438
Midili *et al*.	0.9984	1.3884E-04	0.01256	0.9988	1.1247E-05	0.003535	0.9972	1.5569E-04	0.01289

Table 5: Regression coefficients and standard deviations of thin layer drying models for CHP at 100% load.

100%									
Model	3 mm			5 mm			7 mm		
	R^2	X^2	RMSE	R^2	X^2	RMSE	R^2	X^2	RMSE
Newton	0.9996	3.2195E-05	0.005674	0.9936	5.0107E-04	0.02369	0.9964	2.1600E-04	0.0147
page	0.9996	3.2063E-05	0.005818	0.9982	1.4107E-04	0.01283	0.9983	1.0529E-04	0.01042
Modified Page	0.9996	3.2063E-05	0.005818	0.9982	1.4107E-04	0.01283	0.9983	1.0529E-04	0.9983
Wang and Singh	0.9431	0.00464105	0.06999	0.9895	8.2321E-04	0.03099	0.9948	3.1206E-04	0.01793
Modified Henderson and Pabis	0.9996	3.2179E-05	0.005828	0.995	3.9464E-04	0.02146	0.9975	1.4879E-04	0.01238
Logaritmic	0.9996	3.2174E-05	0.005997	0.9975	1.9375E-04	0.01536	0.9986	8.2824E-05	0.00948
Approximation of diffusion	0.9996	3.1837E-05	0.005965	0.9936	5.0107E-04	0.01522	0.9985	8.8912E-05	0.009717
Modified Page 2	0.9996	3.2063E-05	0.005986	0.07306	2.1086E-02	0.01602	0.9983	1.3474E-04	0.01057
Midili *et al*.	0.9505	0.00403789	0.005932	0.9984	1.2396E-04	0.01256	0.9987	7.6235E-05	0.009144

Conclusion:

The drying process of orange slice was comprehensively investigated in this research. Several temperature and air velocity were employed to achieve a precise idea of drying of orange slice in CHP dryer. Furthermore, the Midilli *et al*. model fitted best to the experimental data compared to the other standard models reported on drying of agricultural products. It is found that the drying curves of orange slice demonstrated the falling rate period. Compared with the effect of air velocity, the effect of temperature was significant on the drying time for fresh orange slice; on the other hand, by increasing air temperature at constant air velocity, the drying time decreased.

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