

# INFRARED DRYING OF APRICOT POMACE

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**Abstract**—Effect of infrared powers (62, 74, 88, 104 and 125 W) on drying kinetics of apricot pomace was investigated. It is observed that drying characteristics of apricot pomace were greatly influenced by infrared power. Henderson and Pabis model was investigated for describing thin-layer drying of apricot pomace. The model because of the high coefficient of determination ( $R^2$ ) as well as the lowest reduced chi-square ( $\chi^2$ ) and root mean square error (RMSE) values adequately described the experimental data of apple pomace drying. Effective moisture diffusivity ( $D_{eff}$ ) values were increased by increasing infrared power and changed between  $1.67 \times 10^{-9}$  and  $6.03 \times 10^{-9}$  m<sup>2</sup>/s. Activation energy was estimated by a modified Arrhenius type equation and found to be 2.32 kW/kg. The colour results were affected by drying conditions.

**Keywords**—Apricot pomace, colour, effective moisture diffusivity, infrared drying, mathematical modelling.

## I. INTRODUCTION

Losses in food production chain of agricultural products in general comprise these five steps: agricultural production stage, post-harvest processing and storage, food processing and packaging stage, which occurs in the distribution and consumption-stage (HLPE, 2014). Evaluation of food waste is of vital importance in terms of environmental impact and protection of natural resources. Rapid microbial spoilage due to the high-water content of food waste is the high transport and storage costs limit the opportunities of different assessment. The wastes are generally used in the some industry such as animal feed industry for animal feed and feed additives, the agricultural industry for manure and compost, food and pharmaceutical industries for the acquisition of functional compounds such as dietary fibre, pectin, unsaturated fatty acids, flavonoids, and also fuel production (Sui *et al.*, 2014; Ribeiro *et al.*, 2015; Stancu *et al.*, 2016; Deamicci *et al.*, 2016).

Fruit juice industry has a large quantity of wastes, such as peel, seed, pomace, rags and kernels. In the apricot juice processing, the apricot pomace consists of pulp and apricot kernel. Ucuncu *et al.* (2013) reported that the apricot pomace contains 22% reduced sugar, mainly glucose and fructose, 1.29% protein, 14.6% total dietary fibre, and 0.79% ash.

Consumers pay attention to the use of high-quality products and new drying technology to reduce energy use, which will set the stage for competition to meet the demands of manufacturers on the market (Riadh *et al.*, 2015). Sun drying is the most common technique used since ancient times. The transfer of heat energy by

convection, conduction and radiation although three main methods; hot air convective drying technique is the most widely used method. Infrared drying has gained popularity as an alternative drying method for a variety of agricultural products. Infrared energy incident on the food material creates changes in electronic, vibrational and rotational states at atomic and molecular levels, without heating the surrounding air (Moses *et al.*, 2014). Infrared drying could save up 50% energy compared to convective drying (Chen *et al.*, 2015). In recent years, it has become popular because of short drying time, high thermal efficiency and many advantages to obtain high quality products. Moreover, initial setup and the low operating costs, in the pre-drying stage by the drying process or the combined system is easy to integrate, applicable to ensure uniform temperature distribution at different wavelengths and power easy control of operating parameters. It also provides opportunities for different purposes such as short drying time, reduction of energy consumption, ensuring high thermal efficiency, good quality regardless of seasonal factors and good drying environment independent of tight spaces, pre-drying, drying, pasteurization, sterilization, baking, dissolving and roasting (Das *et al.*, 2009; Motevali *et al.*, 2011; Pawar and Pratepe, 2015).

The chemical and physical changes that occur during the drying process, the drying equipment and the drying method are important to understand the effect of the mathematical modeling of the microscopic nature of product moisture transfer. Thin-layer drying models can be categorized as theoretical, semi-theoretical and empirical. Various studies on mathematical modeling of fruit and vegetable pomace, by-product and waste are presented in the literature, including hot-air convective drying of apple, carrot, olive and watermelon pomaces (Wang *et al.*, 2007; Kumar *et al.*, 2012; Oberoi and Sogi, 2015), microwave drying of tomato pomace (Al-Harabsheh *et al.*, 2009), infrared drying of apple pomace, tomato by-product and grape pomace (Sui *et al.*, 2014; Celma *et al.*, 2009). However, there is no information about drying of apricot pomace with infrared radiation. The main objectives of this study were to investigate the effect of infrared power on the drying rate and time, fit the experimental data to ten thin-layer drying models, and compute effective moisture diffusivity of apricot pomace.

## II. MATERIALS AND METHODS

### A. Sample Preparation

Fresh apricot pomace were obtained from Döhler Fruit juice company in Karaman at June 2015 and kept in a refrigerator (Arcelik 1050T, Eskisehir, Turkey) at 4°C

prior to use. The initial moisture content of the fresh apricot pomace was determined according to the method described by AOAC 934.06 (AOAC, 1990), was 4.6179 kg water / kg dry matter (d.b.).

### B. Drying Procedure

Drying experiments were carried out in a moisture analyzer with one 250 W halogen lamp (Snijders Moisture Balance, Snijders b.v., Tilburg, Holland). In the infrared drying process, the sample should be separated evenly and homogeneously over the entire pan. The drying experiments were performed at infrared power level varying from 62 to 125 W. The power level was set in control unit of equipment. Moisture loss in the samples with initial load of  $75 \pm 0.2$  g was measured with a digital balance (Mettler-Toledo AG, Grefensee, Switzerland, model BB3000) with accuracy of 0.1 g and recorded at 30 min intervals. Drying was stopped when the moisture content of samples was approximately 0.05 kg water / kg dry matter (d.b.). The dried product was cooled and packed in low-density polyethylene bags that were heat-sealed. The experiments were triplicated.

### C. Mathematical Modelling

The moisture content of apricot pomace was calculated by the following equation:

$$M = \frac{W_i - W_d}{W_d} \quad (1)$$

where  $M$  is the moisture content (kg water/kg dry matter),  $W_i$  is the weight of sample (kg), and  $W_d$  is the dry matter content of sample (kg).

The moisture ratio ( $MR$ ) of the apricot pomace during drying experiments was calculated by using Eq. (2):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

where  $M_t$ ,  $M_0$  and  $M_e$  are moisture content at any time, initial moisture content, equilibrium moisture content (kg water/kg dry matter), respectively, and  $t$  is drying time (min). The equilibrium moisture content ( $M_e$ ) is relatively small compared with  $M_0$ , especially for infrared drying. Therefore,  $M_e$  was numerically set to zero in this study. So  $MR$  can be simplified to  $MR = M_t/M_0$  (Fahloul *et al.*, 2009; Calín-Sánchez *et al.*, 2014).

The drying rate ( $DR$ ) was calculated using Eq. (3):

$$DR = \frac{M_t - M_{t+dt}}{dt} \quad (3)$$

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

Fick's second law of diffusion equation was used to fit the experimental drying data for the determination of effective moisture diffusivity coefficients.

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2 M}{\partial x^2} \quad (4)$$

where  $M$  is the moisture content (kg water/kg dry matter),  $t$  is the drying time (s),  $x$  is the distance in the solid (m), and  $D_{eff}$  is the effective moisture diffusivity ( $m^2/s$ ).

The solution of diffusion Eq. (4) for slab geometry was solved by Crank (1975) and supposed uniform initial moisture distribution, negligible external resistance,

constant temperature and diffusivity, and negligible shrinkage:

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

where,  $L$  is the half-thickness of sample (m) and  $n$  is a positive integer. The Henderson and Pabis model is the first term of general series solution of Fick's second law of diffusion equation (Henderson and Pabis, 1961):

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (6)$$

Equation (6) can also be written in a more simplified form as:

$$MR = a \exp(-kt) \quad (7)$$

### D. Data Analysis

Data was analyzed using Statistica 8.0.550 (StatSoft Inc., Tulsa, OK, USA) software package. The parameters of model were estimated using a non-linear regression procedure based on the Levenberg-Marquardt algorithm. The fitting quality of the experimental data to the model was evaluated using the coefficient of determination ( $R^2$ ), reduced chi-square ( $\chi^2$ ), and root mean square error ( $RMSE$ ). The  $R^2$ ,  $\chi^2$  and  $RMSE$  were calculated from the following formulas:

$$R^2 = 1 - \frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^N (\overline{MR}_{pre} - MR_{exp,i})^2} \quad (8)$$

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (9)$$

$$RMSE = \left[ \frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (10)$$

where  $MR_{exp,i}$  and  $MR_{pre,i}$  are experimental and predicted dimensionless moisture ratios, respectively,  $N$  is number of observations, and  $z$  is number of constants. The best model was chosen based on the highest value of  $R^2$  and the least values of  $\chi^2$ , and  $RMSE$  (Chen *et al.*, 2015).

### E. Computation of Activation Energy

Activation energy ( $E_a$ ) represents the minimum energy required for water molecules to migrate within the food during drying (Martynenko and Kudra, 2016). For the calculation of activation energy, modified form of Arrhenius equation as generally described in literature shows the relationship between the effective moisture diffusivity and the infrared power level to sample weight (Dai *et al.*, 2015).

$$D_{eff} = D_0 \exp\left(-\frac{E_a m}{p}\right) \quad (11)$$

where  $D_0$  is the pre-exponential factor of Arrhenius equation ( $m^2/s$ ),  $E_a$  is the activation energy (W/kg),  $p$  is the infrared power level (W) and  $m$  is the sample weight (kg).

## F. Color Measurements

Color measurements were taken on Minolta (Chroma Meter-CR-400 from Konica Minolta, Osaka, Japan) instrument. Total color change ( $\Delta E$ ) and Chroma ( $C$ ) were calculated the following equations (Adak *et al.*, 2017).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (12)$$

$$\Delta L = L - L_0, \Delta a = a - a_0, \text{ and } \Delta b = b - b_0$$

where  $L_0$ ,  $a_0$  and  $b_0$  are color values of the fresh pomace.

$$C = (a^2 + b^2)^{1/2}. \quad (13)$$

## III. RESULTS AND DISCUSSION

### A. Drying Curves

Moisture content of apricot pomace was 4.6179 kg water / kg dry matter dried until about 0.05 kg water / kg dry matter at different powers. The effect of infrared power on drying curves of the apricot pomace is shown in Fig. 1.

The drying curves were typical of similar agricultural products. The moisture content decreased exponentially with elapsed duration of drying and decreased faster at higher infrared powers in all cases, as expected. The drying time decreased greatly when the infrared power level increased. The drying time that required to reach the final moisture content of samples were 450, 390, 240, 180 and 150 min at the infrared power levels of 62, 74, 88, 104 and 125 W, respectively. The average drying rate increased 3 times as the infrared power increased from 62 W to 125 W. As expected at higher infrared power the higher heat absorption resulted in higher product temperature, higher mass transfer driving force, faster drying rate and consequently lesser drying time (Ponkham *et al.*, 2012; Riadh *et al.*, 2015; Kocabiyik *et al.*, 2015; Doymaz, 2016).

The drying rate curves of apricot pomace are shown in Fig. 2.

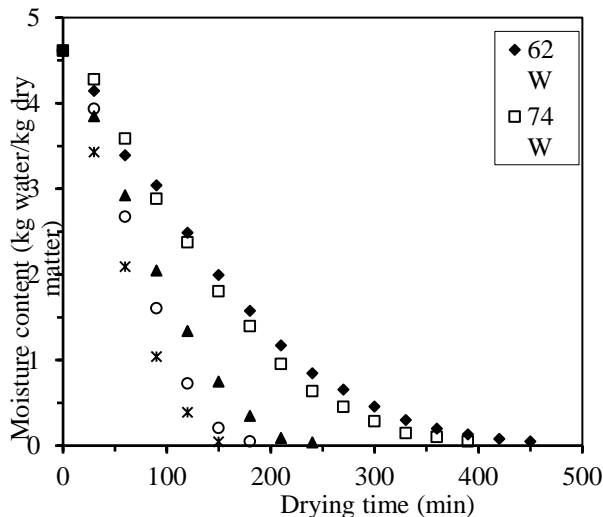


Figure 1. Drying curves of apricot pomace at different infrared powers.

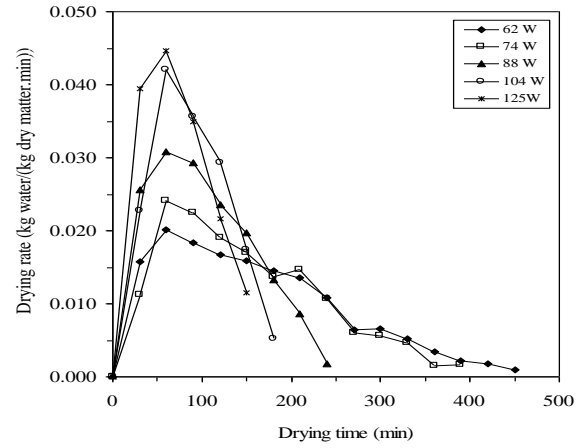


Figure 2. Drying rate vs. time for apricot pomace.

**Table 1.** The results of regression analysis

Power (W)	Model coefficients	$R^2$	$\chi^2$	RMSE
62	a: 1.078366; k: 0.006769	0.9803	0.002324	0.163180
74	a: 1.105065; k: 0.007409	0.9721	0.003661	0.193622
88	a: 1.076304; k: 0.011117	0.9658	0.005236	0.178480
104	a: 1.089134; k: 0.013233	0.9426	0.010677	0.216322
125	a: 1.052809; k: 0.016020	0.9653	0.006574	0.151906

The drying rate increased with increasing air temperature. At the beginning of the drying processes, drying rate increased especially at high air temperatures due to high moisture content of the sample, where liquid vaporization took place within the sample. This creates a large vapor pressure difference between the center and the surface of products. Then, the evaporation of free water could cause the cooling of the sample and, hence, decreasing the drying rate (Horuz *et al.*, 2018).

A constant drying rate period was not observed in all cases, all drying process took place in the falling drying rate period. Therefore, internal mass transfer resistance controls the drying time. Similar results have been reported in the literature for drying of agricultural products such as apricot (Igual *et al.*, 2012), carrot pomace (Kumar *et al.*, 2012), and apple pomace (Wang *et al.*, 2007). From Fig. 2, the increase of drying rate is observed with the increase of infrared power level. This means, at high power levels the heat and mass transfer is higher and the water loss is more excessive. During drying process, the drying rates were higher in the beginning of the process, and after that decreased with decrease of moisture content in the samples. The reason for reduction of drying rate might due to reduction in porosity of samples due to shrinkage with advancement, which increased the resistance to movement of water leading to further fall in drying rates (Singh *et al.*, 2006). The results were consistent with observations made by different authors on drying various agricultural products (Chen *et al.*, 2015; Li *et al.*, 2015).

### B. Evaluation of the Model

The moisture content data of obtained at different infrared powers were converted into the MR and fitted to Henderson & Pabis model (Eq. 7). Results of the statistical computing are shown in Table 1. The values of  $R^2$  were above 0.94. The statistical parameter estimations showed

that values of  $R^2$ ,  $\chi^2$ , and RMSE were ranged from 0.9426 to 0.9806, 0.002324 to 0.010677, and 0.151906 to 0.216322, respectively. To validate the selected model, plots of experimental MR and predicted MR by Henderson & Pabis model are shown in Fig. 3.

Obviously, a good agreement was observed between experimental and predicted MR values. That is, the data points generally banded around a 45° straight line on the plots. The prediction applying the model indicated the fact that moisture ratio values surround the straight line, which consequently demonstrates the pertinence of this model to describe drying characteristics of apricot pomaces. The Henderson & Pabis model was also suggested by Iguaz *et al.* (2003).

### C. Effective Moisture Diffusivity

The effective moisture diffusivity ( $D_{eff}$ ) values for different infrared power levels are calculated from Eq. (6). The  $D_{eff}$  values are given in Fig. 4 and ranged from  $1.67 \times 10^{-9}$  to  $6.03 \times 10^{-9}$  m<sup>2</sup>/s.

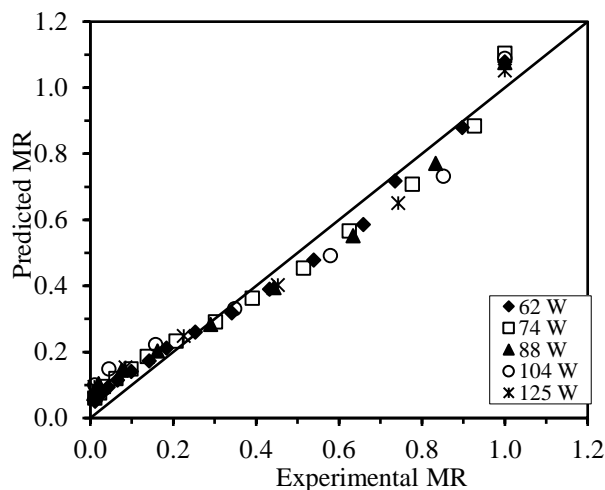


Figure 3. Experimental and predicted moisture ratio from the Henderson & Pabis model distributions of apricot pomace

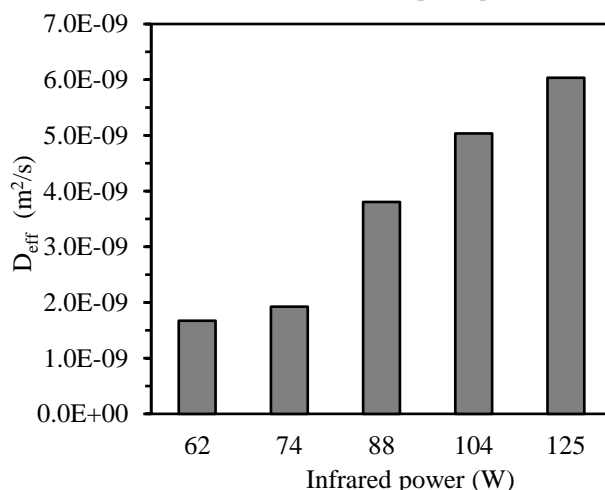


Figure 4. Effective moisture diffusivity versus infrared power.

It can be seen that values of  $D_{eff}$  increased greatly with increasing infrared power level. This may be because, the increase in power level caused rapid rise in temperature of the apricot pomace, which in turn increased the vapour

pressure. As result, it led to faster drying. Drying at 125 W has the highest value of effective moisture diffusivity and the lowest value was obtained for 62 W. The  $D_{eff}$  values of the apricot pomace were within the general ranges of  $10^{-12}$  to  $10^{-8}$  m<sup>2</sup>/s for biological materials (Zogzas *et al.*, 1996). The effect of infrared power on effective moisture diffusivity is defined by the following equation:

$$D_{eff} = 1 \times 10^{-9} p + 1 \times 10^{-10} \quad (R^2 = 0.9656) \quad (14)$$

### D. Activation Energy

The activation energy can be determined from the slope of Arrhenius plot,  $\ln(D_{eff})$  versus  $m/p$  (Eq. 11). The  $\ln(D_{eff})$  as a function of the sample weight/infrared power level was plotted in Fig. 5.

The results show a linear relationship due to Arrhenius type dependence. Equation (15) shows the effect of sample weight/infrared power on  $D_{eff}$  of samples with the following coefficients:

$$D_{eff} = 2.516 \times 10^{-8} \exp\left(-\frac{2320.8 m}{p}\right) \quad (R^2 = 0.9468) \quad (15)$$

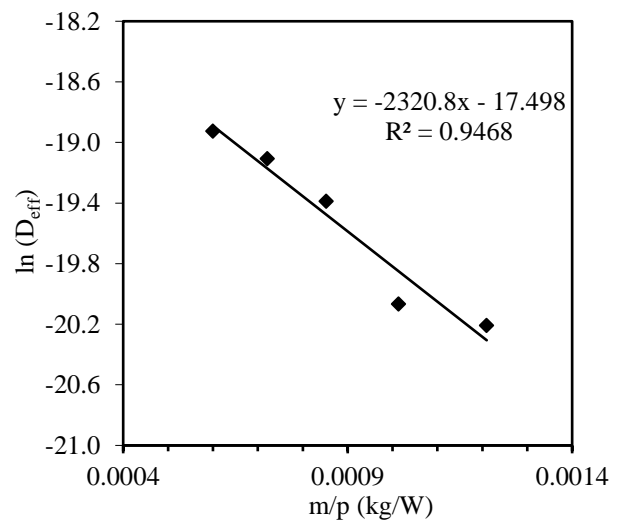


Figure 5. Arrhenius-type relationship between effective moisture diffusivity and infrared power

**Table 2.** The colour values of fresh and dried apricot pomaces

Power (W)	L	a	b	$\Delta E$	C
62	31.39	11.96	18.48	7.95	22.01
74	30.78	11.94	18.62	8.04	21.60
88	29.39	11.58	15.99	8.25	19.74
104	25.08	9.62	13.48	8.77	16.56
125	21.83	8.07	8.31	9.32	11.58

The estimated values of  $D_0$  and  $E_a$  from modified Arrhenius type exponential Eq. (15) are 2.32 kW/kg.

### E. Colour

Colour of dried fruits and vegetables can indicate retention of the pigment nutrients as carotenoids, flavonoids, phenols, chlorophyll and betalains (Aral and Bese, 2016). These changes of values of L, a, and b may be due to degradation of pigments or nonenzymatic Maillard

browning (Garcia-Martinez *et al.*, 2013). The colour values such as  $L$ ,  $a$ ,  $b$  and chroma ( $C$ ) values for fresh apricot pomace were measured at 65.60, 11.20, 48.24 and 49.52, respectively. The results of colour values obtained from the after drying processes are presented in Table 2. The results showed that all fresh apricot pomace colour parameters ( $L$ ,  $a$ ,  $b$ ,  $\Delta E$  and  $C$ ) changed significantly after infrared drying. The maximum total colour change ( $\Delta E$ ) was 125 W. The colour results showed that the  $L$ ,  $a$ ,  $b$  and chroma values decreased with increasing power level. The similar results were reported by different authors on drying grape pomace (Sui *et al.*, 2014), apricot (Ihns *et al.*, 2011), and kiwifruit (Aidani *et al.*, 2017).

#### IV. CONCLUSIONS

The drying characteristics of apricot pomace were investigated in an infrared dryer at different infrared powers. The drying of apricot pomace at each infrared power occurred in falling-rate period. The drying time significantly decreased with the increase in infrared power. The high  $R^2$ , low  $\chi^2$  and  $RMSE$  indicated the acceptability of Henderson and Pabis model for predicting moisture content. The effective moisture diffusivity values were varied between  $1.67 \times 10^{-9}$  to  $6.03 \times 10^{-9}$  m<sup>2</sup>/s. With the increase of power level, the effective moisture diffusivity increased. Activation energy was estimated to be 2.32 kW/kg. The colour results were affected by drying conditions.

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