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Drying kinetics of olive pomace-derived charcoal briquettes with energy consumption

Cinética de secagem de briquetes de carvão derivados de bagaço de oliva com consumo de energia

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Highlights

Drying properties of Olive pomace-derived charcoal briquette samples.
Determination of the optimum drying method and the temperature value.
Determination of the mathematical thin-layer drying model based on experimental data.

Abstract

The drying experiments were performed at different temperatures of the drying air (40, 50, and 60°C) and air velocity of 2.5 and 3.5 m/s. Six thin-layer drying models were evaluated and fitted to the experimental moisture data. The fit quality of the models was evaluated using the determination coefficient, chi-square, and root mean square error. Among the selected models, the Midilli et al. model was found to be the best model for describing the drying behaviour of olive pomace. Charcoal is used as a domestic fuel for cooking and heating in many developing countries. It is an important green source for making barbecue, which is obtained from agricultural waste. Due to less CO_2 emission, it reduces health risk and deforestation. The coal briquette carbonisation production process consists of a carbonisation stage and a forming stage. During the forming stage, the raw material is mixed with a suitable binder. The final stage of the charcoal process after formation is drying. In this study, the drying parameters of charcoal briquettes made from the olive pomace-making process were evaluated. Three different temperatures and velocities were selected for the drying applications. The low temperature drying process was performed at 60, 50, and 40°C with air velocities of 3 and 2.5. The results were in the range of 3 to 8 hours of drying time. The drying data were applied to six different mathematical models, namely [1]Diffusion Approach, [2]Henderson and Pabis, [3]Two term exponential, [4]Midilli et al., [5]Page, and [6]Wang and Singh Equation Models. The performances of these models were compared according to the coefficient of determination (R^2), standard error of estimate (SEE),

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and residual sum of squares (RSS) between the observed and predicted moisture ratios. The Midilli et al. Diffusion Approach, and Page models described the drying curve satisfactorily in all drying methods.
Key words: Charcoal. Briquette. Drying. Modelling.

Resumo

Os experimentos de secagem foram realizados em diferentes temperaturas do ar de secagem (40, 50 e 60°C) e velocidades do ar de 2,5 e 3,5 m/s. Seis modelos de secagem em camada delgada foram avaliados e ajustados aos dados experimentais de umidade. A qualidade do ajuste dos modelos foi avaliada por meio do coeficiente de determinação, qui-quadrado e raiz quadrada média do erro. Dentre os modelos selecionados, o Midilli et al., modelo foi considerado o melhor modelo para descrever o comportamento de secagem do bagaço de azeitona O carvão vegetal é usado como combustível doméstico para cozinhar e aquecer em muitos países em desenvolvimento. É uma importante fonte verde para a confecção de churrasco, obtido a partir de resíduos agrícolas. Devido à menor emissão de CO_2, reduz riscos saudáveis e desmatamentos. O processo de produção da carbonização do briquete de carvão consiste em uma etapa de carbonização e uma etapa de conformação. Durante a fase de formação, a matéria-prima é misturada com um aglutinante adequado. A etapa final do processo de carvão vegetal após a formação é a secagem. Neste estudo foram avaliados os parâmetros de secagem do briquete de carvão vegetal a partir do processo de fabricação de bagaço de azeitona. Três diferentes temperaturas e velocidades foram selecionadas para aplicações de secagem. O processo de secagem a baixa temperatura foi realizado aos 60; 50 e 40 C ° com velocidade do ar de 3; e 2.5. Os resultados obtidos ficaram na faixa de 3 a 8 horas de tempo de secagem. Os dados de secagem foram aplicados a seis modelos matemáticos diferentes, a saber; [1]Abordagem de difusão, [2]Henderson e pabis, [3]Exponencial de dois termos, [4]Midilli et., al., [5]Página [6]Modelos de equações de Wang e Singh. Os desempenhos desses modelos foram comparados de acordo com o coeficiente de determinação (R^2), erro padrão da estimativa (SEE) e soma dos quadrados residuais (RSS), entre as razões de umidade observadas e previstas. Verificou-se que os modelos Midilli et al., Diffusion Aproach e Page descreveram a curva de secagem de forma satisfatória em todos os métodos de secagem.
Palavras-chave: Carvão. Briquete. Secagem. Modelagem.

Introduction

Biomass is the third primary global energy source, after coal and oil, and is a major contributor to world energy resources (Demirbas, 2010; Sugumaran & Seshadri, 2010). Increased world population and industrial activity in recent decades have resulted in an immense amount of biomass waste, many of which have harmful characteristics when disposed of directly and improperly in the atmosphere (Oliveira et al., 2017). Moreover, biomass energy is considered a renewable energy source, which is an alternative to fossil fuel sources and has a growing number of environmental and economic adverse effects on the environment. There is a considerable biomass source after agricultural, forestry, and industrial processes, which include products, by-products, residues, and wastes.

Olive oil production generates huge quantities of high-polluting by-products, namely wastewater and solid waste (Ouazzane et al., 2017). Olive pomace is obtained from the extraction of olive oil and mainly consists of solid residue and a significant quantity of water, which represents 20–50% of the total weight of the processed olives (Bouknana et al., 2014). This material has several adverse effects on the environment, both in the agricultural and olive oil production phases (Salomone & Ioppolo, 2012). To avoid the environmental effects of the olive oil production system, it is very important to recover olive pomace. One of the recovery options is to make a charcoal briquette from olive pomace.

Sales of charcoal briquettes could have easily expanded in the market. Charcoal is a desirable fuel because of its non-smokeless fire, prolonged heat, and less health risk. Wood charcoal is made from hardwoods, such as oak, hornbeam, beech, olive, and citrus, and is produced and consumed in most of Turkey to grill and barbecue. The average annual consumption of charcoal for grilling and barbecue is estimated to be over 250,000 tonnes in Turkey (Menemencioglu, 2013).

The charcoal-making process consists of seven stages, including crashing, carbonising, crashing, screening, forming of briquette and drying process (Zubairu & Gana, 2014). Charcoal briquettes contain a high moisture content after they are pressed or moulded, which is not suitable for the storage and transportation of biomass. This moisture content should be reduced during the manufacturing process of the briquettes by drying the briquettes in a furnace. The moisture content is a major quality characteristic of charcoal, and a suitable moisture content is below 10% before sale (Oliveira et al., 2017). Therefore, the drying characteristics of charcoal briquettes under different operational conditions should be studied.

Many studies on the drying of olive pomace have been investigated previously (Akgun & Doymaz, 2005; Arjona et al., 1999; Difonzo et al., 2021; Doymaz et al., 2004; Gögüs & Maskan, 2001, 2006; Göker et al., 2021). Akgun and Doymaz (2005) used a cabinet-type dryer to study the drying and modelling of olive pomace over a wide temperature range using mathematical models. Arjona et al. (1999) studied the drying process of olive pomace in a laboratory drying tunnel, and the drying rate was determined with respect to operating conditions (temperature and air velocity) and agglomerate size. Difonzo et al. (2021) investigated the extraction methods with supercritical carbon dioxide of functional phytocompounds from olive pomace samples subjected to two drying methods: freeze drying and hot-air drying. Doymaz et al. (2004) and Göker et al. (2021) studied the formation kinetics of polycyclic aromatic hydrocarbons during drying of olive pomace at 170, 200, and 230°C until the final moisture of 5%. Gögüs and Maskan (2001) studied the effects of microwave power, thickness, and temperature on the drying of olive pomace in a microwave oven. Using a pilot plant tray dryer, Gögüs and Maskan (2006) investigated the drying characteristics of olive pomace as a function of sample thickness, particle size, and drying air temperature. However, to the best of the authors' knowledge, there are no publications on the kinetics of olive pomace-derived charcoal briquettes, and much less is known about how drying air temperature and air velocity affect the kinetics of drying and energy consumption of the drying process of olive pomace-derived charcoal briquettes.

The main goal of this research was to explore the effect of drying air temperature and air velocity on the drying kinetics of olive pomace-derived charcoal briquettes in a hot air dryer, as well as the energy consumption and efficiency of the drying process, and to fit the experimental moisture data to various mathematical models available from the literature.

Materials and Methods

Materials

Carbonised olive pomace was used as a raw material in making charcoal briquettes and was mixed with cellulose-based adhesive. Charcoal briquettes were made in local firms. A representative view of the hollow core cylindrical briquette used in the trial is given in Figure 1.

Figure 1. Schematic view of olive pomace derived charcoal briquette

Drying procedure

The laboratory hot air dryer (Figure 2) consisted of a blower (axial fan), which directed air past three electrical resistance-heating coils with one connected to a variable voltage controller. The resistance-heating unit was adjusted and calibrated to operate at three temperatures (40, 50, and 60ºC). The drying chamber unit contained a stacked tray for product drying. The sample was located at the top of the drying chamber on the tray. A K-type thermocouple located in the pipe was used to monitor air temperature. A pitot tube was used to measure the pressure drop for calculating the air velocity in the pipe. The velocity of air was adjusted through an AC driver connected to the blower. The selected air velocities were 1.5, 2.5, and 3 m/s. About 1000 grams of charcoal briquette was subjected to the drying process to determine the drying parameters. The ambient air temperature and relative humidity were measured at 1-hour intervals during drying.

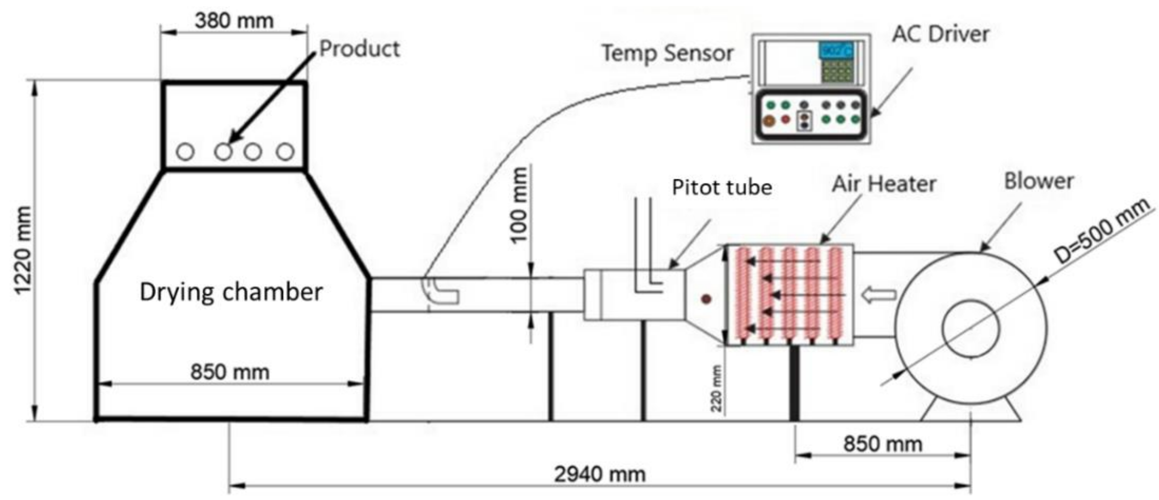

Figure 2. Drying equipment

The mass change of charcoal briquettes was weighed at every 1-hour period throughout the trial. A digital balance (0.01 g sensitivity) was used in the trial. The dryer door was opened and remained open during the period required to remove, weigh, record, and return the tray to the appropriate location in the dryer. The fan and heater continued to operate during this time. When a constant weight was obtained for three consecutive readings, it was concluded that all moisture was volatilised, and the test was terminated. The moisture content of the product to be dried was determined on a wet and dry basis using ASAE standards.

Energy consumption by the dryer

Energy consumption by the hot air-drying system (Etot) was determined by the total energy consumed by the heaters (thermal energy) and the blower (mechanical energy). The thermal energy consumed by the heaters was calculated using Eq. 1 (Motevali et al., 2014; Vieira et al., 2007).

$$EU_{ter} = (Q_{air} \cdot \rho_{ma} \cdot C_{pma} \cdot \Delta T) \cdot t \quad (1)$$

where Qair is the volumetric air flow rate (m^3 s^{-1}), ρma is the density of moist air (kg m^{-3}), Cpma is the specific heat capacity of moist air (kJ kg^{-1} K^{-1}), ΔT is the temperature difference (°C), and t is the total time for drying each sample (s).

The volumetric air flow rate was obtained from Eq. 2:

$$Q_{air} = A.V \quad (2)$$

where A and V are the drying bed area (m^2) and air flow rate (m s^{-1}), respectively.

The specific heat capacity of moist air (Cpma) was calculated using Eq. 3 (Tsilingiris, 2008):

$$C_{pma} = \frac{(C_{pda} + C_v X)}{1+X} \quad (3)$$

where Cpda, Cv and X are specific heat of dry air (kJ kg^{-1} K^{-1}), specific heat of water vapour (kJ kg^{-1} K^{-1}) and absolute humidity of moist air (kg water/kg dry air), respectively, and are defined as follows (Zare et al., 2006):

$$C_{pda} = 1.04841 - (3.83719\,x\,10^{-4}T) + (9.45378\,x\,10^{-7}T^2) - (5.49031\,x\,10^{-10}T^3) + (7.9298\,x\,10^{-14}T^4) \quad (4)$$

$$C_v = 1.883 - (1.6737\,x\,10^{-4}T) + (8.4386\,x\,10^{-7}T^2) - (2.6966\,x\,10^{-10}T^3) \quad (5)$$

where T is the air temperature (K).

Relative air humidity was determined based on the following equation:

$$RH = \frac{(101.3X)}{0.62189P_{vs} + XP_{vs}} \quad (6)$$

where P_{vs} is the saturated vapour pressure (kPa) and is derived as a function of the absolute temperature (Naghavi et al., 2010):

$$P_{vs} = 0.1\,exp(27.0214 - \frac{6887}{T} - 5.31\,ln\,ln\,(\frac{T}{273.16})) \quad (7)$$

The density of moist air (ρma) was determined using Eq. 8 (Tsilingiris, 2008):

$$\rho_{ma} = \rho_{da}\left[\frac{1+X}{1+\frac{R_v}{R_a}X}\right] \quad (8)$$

where ρma, Rv and Ra are the density of moist air (kg m^{-3}), gas constant for water vapour (0.462 kJ kg^{-1} K^{-1}) and gas constant for dry air (0.287 kJ kg^{-1} K^{-1}), respectively. Additionally, ρda is the density of dry air (kg m^{-3}), and it was calculated as follows (Naghavi et al., 2010):

$$\rho_{da} = \frac{101.325}{0.287T_{abs}} \quad (9)$$

The mechanical energy consumed by the blower was calculated using Eq. 10 (Motevali et al., 2014).

$$E_{mec} = \Delta P . Q_{air} . t \quad (10)$$

where E_{mec} and ΔP are mechanical energy (kJ) and pressure drop (kPa), respectively.

The pressure drop for a fluid flowing through a porous column of solid particles at the specified flow rate was determined using the Ergun equation (Eq. 11) (Pell, 1990).

$$\frac{\Delta P_b}{L} = 150\left[\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu a\,x\,V}{(\psi\,x\,d_p)^2}\right] + 1.75\left[\frac{1-\varepsilon}{\varepsilon^3}\frac{\rho_{ma}\,x\,V^2}{\psi\,x\,dp}\right] \quad (11)$$

where Δ_{Pb} is the pressure drop across the bed (Pa), L is the length of the bed (m), d_p is the equivalent diameter of particles (m), ψ is the sphericity of particles (dimensionless), and ε is the bed porosity (dimensionless). μ_a is the dynamic viscosity of the drying air (Pa s), which is defined as follows:

$$\mu_a = 1.691 \times 10^{-5} + 4.984 \times 10^{-8} T - 3.187 \times 10^{-11} T^2 + 1.319 \times 10^{-14} T^3 \quad (12)$$

Specific energy consumption

Specific energy consumption in the drying process can be defined as the required energy to remove 1 kg of water from the moist materials (kWh kg^{-1}) and was calculated using Eq. 13.

$$SEC = \frac{E_{tot}}{m_w} \quad (13)$$

Mathematical modelling

The moisture content of drying charcoal at time t can be transformed into the moisture ratio (MR):

$$\mathrm{MR} = \frac{M_t - M_e}{M_0 - M_e} \quad (14)$$

where Mt, M_0 and M_e are moisture content at any time of drying (kg water/kg dry matter), initial moisture content (kg water/kg dry matter) and equilibrium moisture content (kg water/kg dry matter), respectively.

All moisture contents were reported as wet basis (%, w.b). The simplification of MR in Eq. 1 as M/Mo was suggested by Diamante and Munro (1993) and Elicin and Sacılık (2005) due to the continuous fluctuation of the relative humidity of drying air under solar tunnel dryer conditions. Therefore, the drying rate as g_{water}/h (DR) of the tomato samples was determined using Equation 18.

$$\mathrm{DR} = \frac{\mathrm{M}_{t+dt} - \mathrm{M}_t}{\mathrm{dt}} \quad (15)$$

where M_{t+dt} is the moisture content at *t*+d*t* (g water/g dry matter).

The drying models in Table 1 were used to analyse the moisture variation during the drying process and to determine the best drying model fit with the experimental data.

Table 1
Mathematical equations used for modelling of drying process

	Model name	Model equation	References
1	Diffusion Approach	MR=a exp(-kt)+(1-a)exp(-kbt)	Toğrul and Pehlivan (2003)
2	Henderson and pabis	MR=a exp(-kt)	Akpınar et al. (2006)
3	Two term exponential	MR=a exp(-kt)+(1-a)exp(-kat)	Sharaf-Elden et al. (1980)
4	Midilli-Kucuk	MR=a exp(-k(t^n)+bt	Sacilik and Elicin (2006)
5	Page	MR=exp(-kt^n)	Agrawal and Singh (1977)
6	Wang and Singh	MR=1+at+bt^2	Wang and Singh (1978)

In the above equations, a, b, k, and n are the model coefficients. A non-linear regression method was utilised to fit the data for the selected drying models. The best model describing the drying characteristics of charcoal briquettes was chosen as the one with the highest R^2 (Coefficient of determination) and the lowest SEE (standard error of estim7ate) and RSS (residual sum of square) values. Non-linear regression analysis was performed using the Sigma Plot computer programme.

Results and Discussion

The results of hot air drying of olive pomace-derived charcoal briquettes at a given ambient temperature and relative humidity are given in Table 2. Ambient air temperature and relative humidity in conventional hot air drying play an important role in prolonged drying time and energy consumption. Three different temperatures of 40, 50, and 60ºC and air velocities of 2.5 and 3.5 were applied to the dryer to determine the drying behaviour of charcoal briquettes. While the initial moisture content of the charcoal briquettes was 36.05% (w.b.), the final moisture content varied from 0.12 to 12.27% w.b., depending on the experimental conditions.

Table 2
Drying conditions with initial and final moisture contents of the charcoal briquettes

Air temperature (C°)	Air velocity (m/s)	Ambient temperature (C°)	Relative humidity %	Initial moisture content (w.b)	Final moisture content (w.b.)
60	3.5	36.44	39.08	36.05	5.19
	2.5	35.71	56.42	36.05	4.23
50	3.5	36.44	39.08	36.05	9.18
	2.5	35.44	46.94	36.05	9.29
40	3.5	35.71	56.42	36.05	11.96
	2.5	35.44	46.94	36.05	12.27

Energy consumption for charcoal briquette drying

Values of consumed thermal and mechanical energies for drying of the olive pomace-derived charcoal briquette were calculated using Equations 1, 10, and 13, and the obtained results are presented in Table 3. As seen in Table 3, thermal, and mechanical energy values ranged from 314.91 kJ/kg to 28.87 kJ/kg and from 184.22 kJ/kg to 16.63 kJ/kg, respectively. The minimum values for both thermal and mechanical energies were calculated for a drying air temperature of 40°C with an air velocity of 2.5 m/s application. The application of low temperature and air velocity resulted in lower energy consumption. Higher temperatures and air velocity led to higher thermal and mechanical energy consumption. These results are similar to those of Tohidi et al. (2017) for paddy drying in a bed dryer.

Table 2
Values of consumed thermal, mechanical energies and specific energy consumption for drying of the olive pomace derived briquettes

Air temperature (C°)	Air velocity (m/s)	E_{th} (kJ/kg)	E_{mec} (kJ/kg)	E_{tot} (kJ/kg)	*t* (*h*)	*SEC* (kJ/kg)
60	3.5	134.96	63.63	198.60	3	0.57
	2.5	128.48	31.11	159.60	4	0.38
50	3.5	139.65	110.63	250.29	5	0.63
	2.5	121.96	48.68	170.65	6	0.43
40	3.5	63.42	184.22	247.64	8	0.61
	2.5	45.30	67.53	112.83	8	0.31

The performance of the drying process under different temperatures and air velocities was evaluated using SEC. It provides a link between process conditions and energy consumption for a comparison of the trials. The lower ratio of SEC is preferable owing to the lower energy expenditure per kg of water of the moist materials. Therefore, it is reasonable to select the drying conditions as a "drying air temperature of 40 °C with the air velocity of 2.5 m/s application" based on SEC. However, drying charcoal briquettes under these conditions led to longer drying times (t) of 8 hours (Table 3). In conclusion, the lower SEC resulted in longer drying times.

Drying performance parameters (MR and DR)

The drying parameters of olive pomace-derived charcoal briquettes were explored in detail in terms of MR and DR. The MR and DR as a function of time at an air velocity of 3.5 m/s at temperatures of 40, 50, and 60°C are illustrated in Figure 3. As seen in Figure 3, there were no differences in drying temperatures between 50 and 60°C in terms of drying time, while drying at 40°C lasted one hour more. The drying rates of charcoal briquettes were realised in two stages: increasing and decreasing (Figure 4).

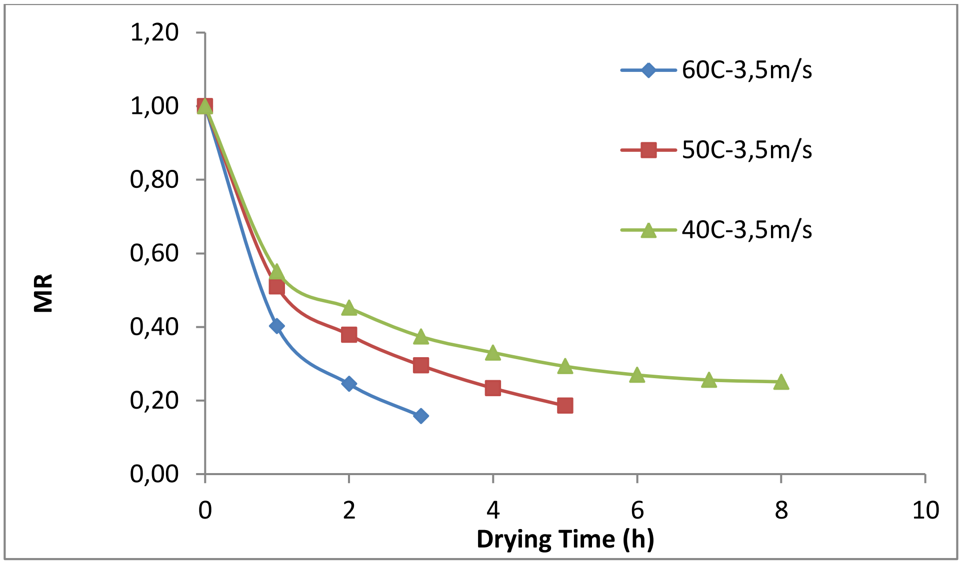

Figure 3. Variation of MR values for 3,5 m/s air velocity.

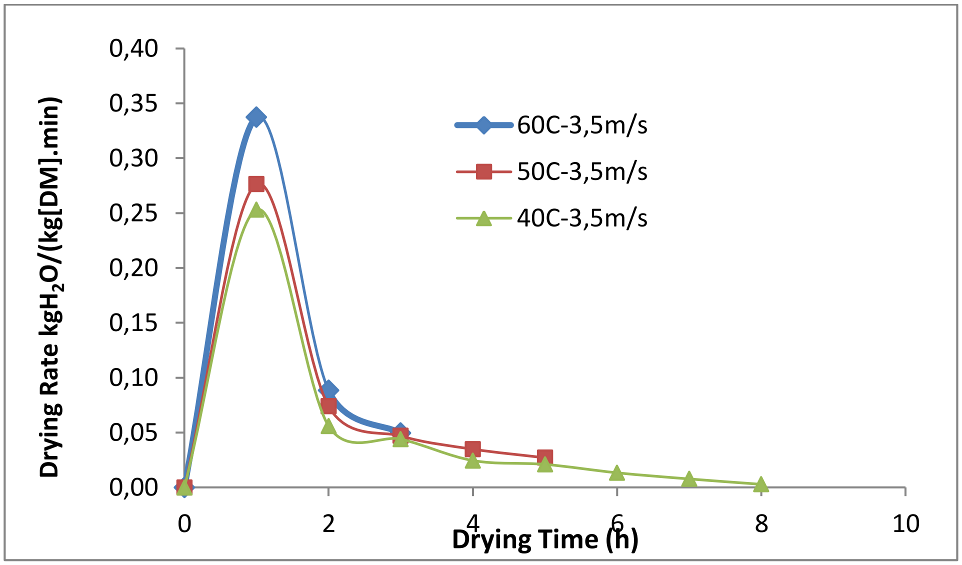

Figure 4. Variation of DR values for 3,5 m/s air velocity.

The drying rates were 0.25, 0.27, and 0.34 kg H_2O/(kg[DM].min) for drying temperatures of 40, 50, and 60°C, respectively, within one hour. In the final stage, the drying rate decreased to 0.003, 0.007, and 0.014 kg H_2O/(kg[DM].min), respectively, for an air velocity of 3.5 m/s. It is expected that the difficulties of heat transfer to the middle of the charcoal briquette will slow down drying rates. Figure 5 shows the MR versus time in a constant value of velocity (2.5 m/s) and different temperatures. Plotted curves are downward slope, which explains the effective moisture diffusivity.

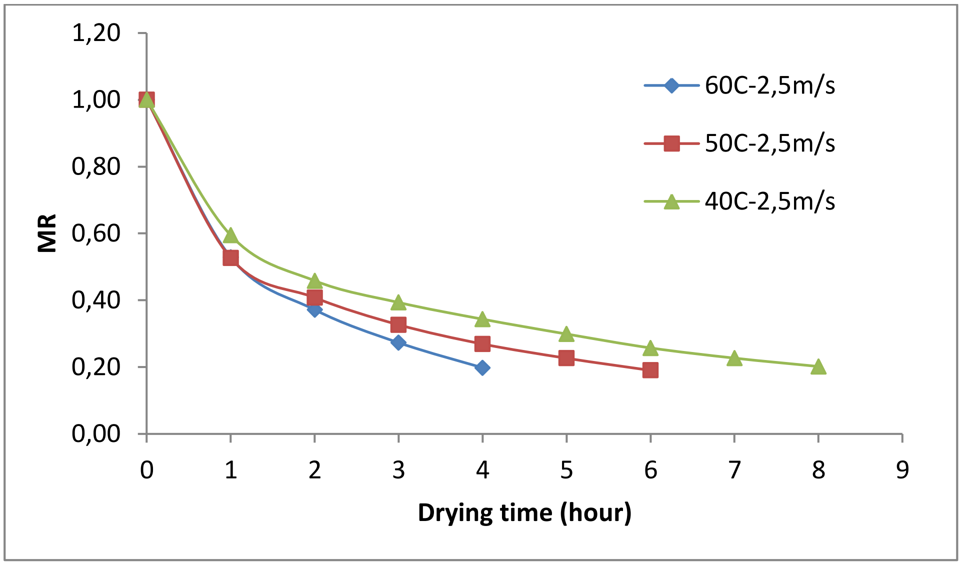

Figure 5. Variation of MR values for 2.5 m/s air velocity.

The drying times of charcoal briquettes were 7 hours for drying temperatures of 50 and 60°C and 8 hours at 40°C. An increase in air temperature led to a decrease in drying times for an air velocity of 3.5 m/s. As shown in Figure 6, the accelerated drying period lasted 1 hour, and the drying period ended with a decreased drying period. The drying of olive pomace briquettes is different from the drying of wet olive pomace, as reported by Meziane (2011). Wet olive pomace is shapeless, but olive pomace briquettes are shaped as cylindrical briquettes.

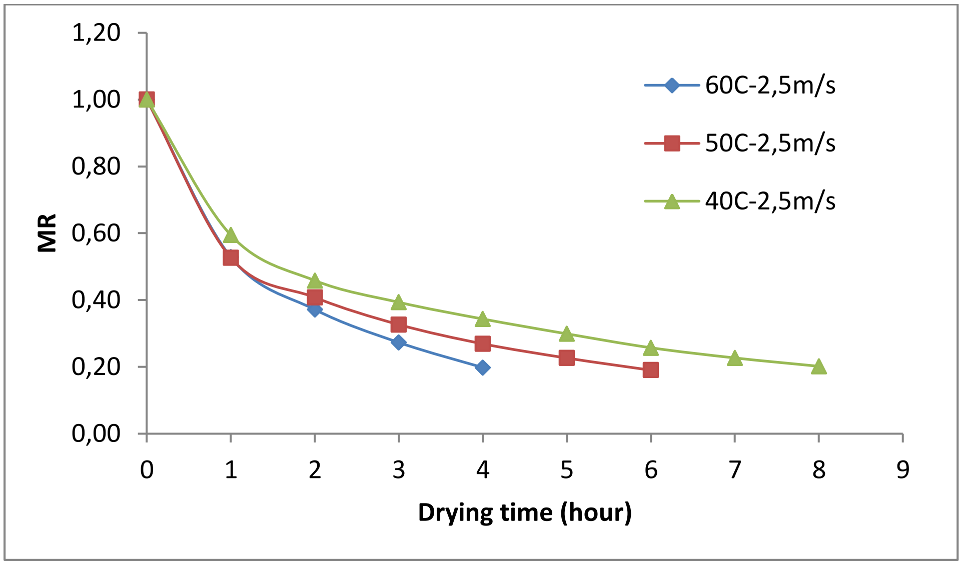

Figure 6. Variation of DR values for 2.5 m/s air velocity.

Drying charcoal in hot air under a 2.5 m/s air flow rate lasted one hour more than the airflow rate of the 3.5 m/s application. This can be explained by the high relative humidity in the drying chamber. Therefore, charcoal briquettes need to be dried at a 3.5 m/s airflow rate or higher.

The mathematical modelling of charcoal briquette was applied to 6 different models evaluated in earlier research. The statistical results are illustrated in Table 4. The results showed that Page's and Midilli et al.'s models were found to best fit the curves at 3.5 m/s airflow rates. The Midilli et al. model was best at a 2.5 m/s airflow rate and 50°C, and the Diffusion Approach was best for 40 and 60°C at a 2.5 m/s airflow rate.

The best model criterion describing the thin-layer drying kinetics was selected according to the highest R2 average values. The lowest RMSE and SEE average values are shown in Table 4.

Table 4
Statistical results obtained from the selected models in all drying experiments

		40 °C			50 °C			60 °C		
		R^2	Adj R^2	SEE(±)	R^2	Adj R^2	SEE(±)	R^2	Adj R^2	SEE(±)
2.5 m/s air flow rate	1	0,9999	0,9999	0,0025	0,9993	0,9991	0,0077	0,9999	0,9999	0,0025
	2	0,9102	0,8973	0,0802	0,9162	0,9057	0,0811	0,9787	0,9761	0,0459
	3	0,94	0,9314	0,0655	0,9462	0,9395	0,0649	0,9938	0,993	0,0249
	4	0,9996	0,9993	0,0067	0,9999	0,9998	0,0037	0,9999	0,9999	0,0032
	5	0,9995	0,9994	0,0061	0,9998	0,9998	0,0039	0,999	0,9989	0,0099
	6	0,8911	0,8755	0,0883	0,8524	0,8339	0,1076	0,8955	0,8825	0,1017
3.5 m/s air flow rate	1	0,9974	0,9965	0,0142	1	0,9999	0,0024	0,9999	0,9999	0,0038
	2	0,8434	0,821	0,1013	0,9431	0,9337	0,0744	0,9797	0,9763	0,0498
	3	0,8734	0,8554	0,0911	0,9709	0,9661	0,0532	0,9925	0,9913	0,0301
	4	0,9995	0,9992	0,0067	1	0,9999	0,0024	0,9999	0,9999	0,0034
	5	0,9986	0,9984	0,0097	0,9996	0,9995	0,0066	0,9999	0,9999	0,0033
	6	0,8579	0,8376	0,0965	0,901	0,8845	0,0981	0,8759	0,8552	0,123

Diffusion Approach was found to best fit the curves at 60 °C and 2,5 m/s airflow rate and Page model was found at 3,5 m/s (Figure 7).

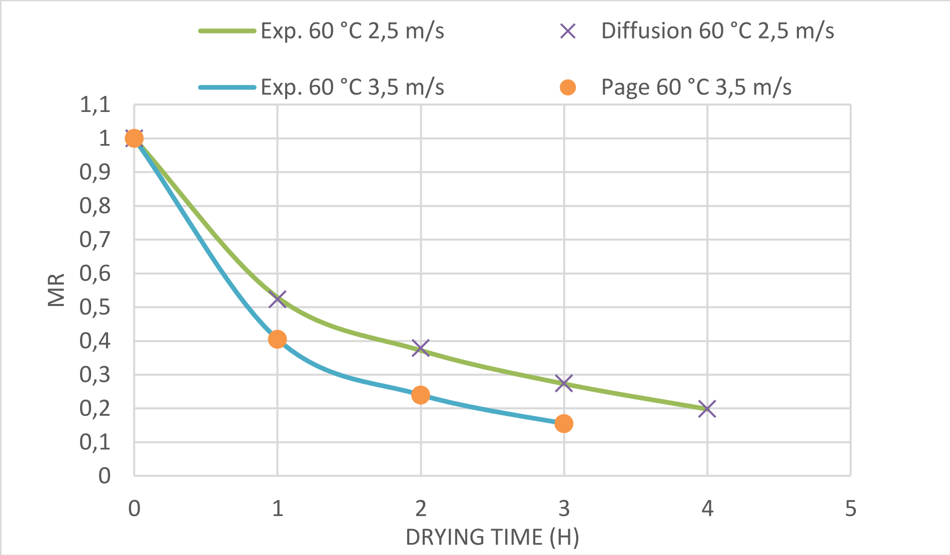

Figure 7. Diffusion Approach was found to best fit the curves at 60 °C and 2,5 m/s airflow rate and Page model was found at 3,5 m/s (Figure 7).

As it is seen at Figure 8, Midilli model was found to best fit the curves for both 2.,5 and 3,5 m/s airflow rate at 50 C°. On the other hand Diffusion Approach and Midilli model were found to best fit the curves at 40 C° and 2,5 and 3,5 m/s airflow rate (Figure 9). These results are in good agreement with other findings reported by Abdelgani et al. for raw olive pomace. They found Midilli et al.'s model to be appropriate for drying raw olive pomace using convective solar drying. In contrast, the mathematical modelling of bio-based charcoal has been scarcely reported. Sridhar and Madhu (2015) found that the best models for Casuarina equisetifolia wood chips were the modified Henderson and Pabis and logarithmic models.

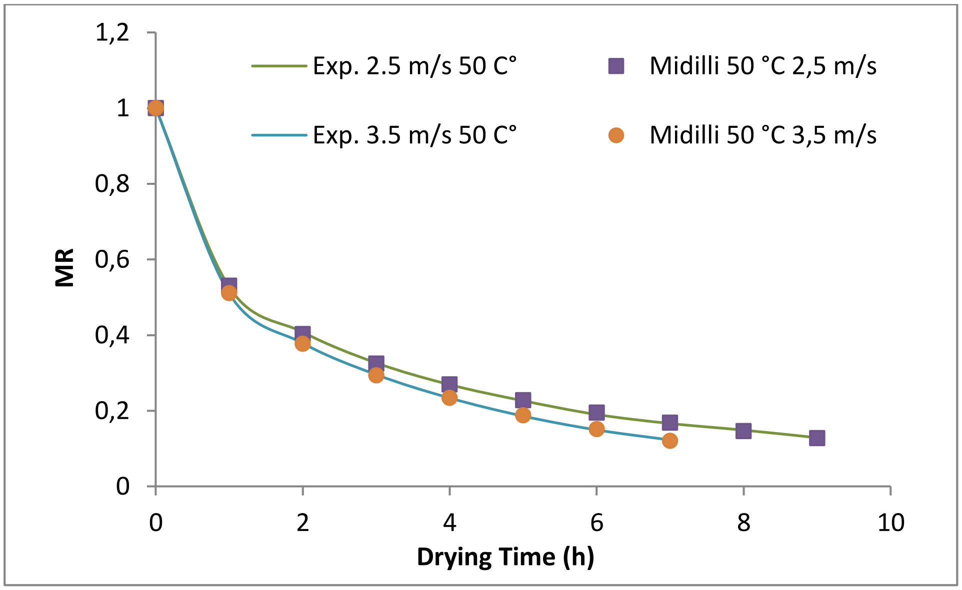

Figure 8. Variation of experimental and mathematical modelling values for 50 C° at different air velocity.

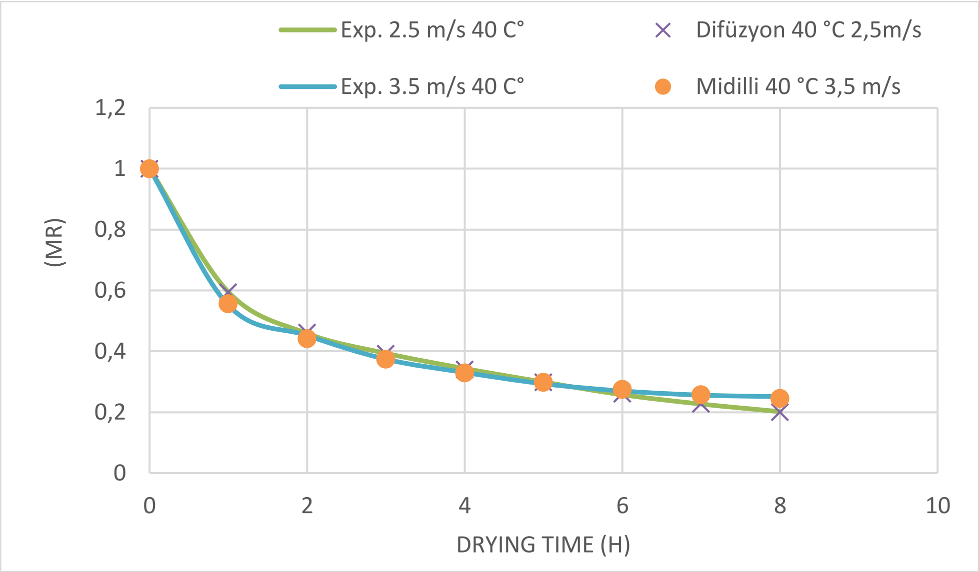

Figure 9. Variation of experimental and mathematical modelling values for 40 C° at different air velocity.

The coefficients of the selected models are shown in Table 5 for the best model describing thin-layer drying of charcoal briquettes. Midilli et al. and Diffusion Approach models gave a good estimation for the drying process.

Table 5
Statistical results obtained from the selected models and Coefficients

Temp (°C)	Air flow rate (m/s)	Model	Coefficients	R^2	Adj R^2	SEE(±)
40	2,5	Diffusion	a= 0,4214 b= 0,0843 k= 1,5771	0,9999	0,9999	0,0025
	3,5	Midilli	a= 0,9998 b= 0,0088 k= 0,6013 n= 0,5120	0,9995	0,9992	0,0067
50	2,5	Midilli	a= 0,9998 b= -0,0016 k= 0,6309 n= 0,5148	0,9999	0,9998	0,0037
	3,5	Diffusion	a= 0,4141 b= 0,1011 k= 2,2517	1	0,9999	0,0024
		Midilli	a= 0,9999 b= -0,0066 k= 0,6586 n= 0,5151	1	0,9999	0,0024
60	2,5	Diffusion	a= 0,3065 b= 0,1170 k= 2,6697	0,9999	0,9999	0,0025
	3,5	Page	n= 0,6585 k= 0,9038	0,9999	0,9999	0,0033

Conclusion

In this study, the drying of olive pomace briquettes was explored in detail, such as drying parameters, mathematical modelling and theoretical energy consumption. Any increment in drying air temperature and velocity caused a decrease in drying time, whereas higher levels of air velocity caused higher energy consumption. The max–min percentages of consumed thermal and mechanical energies in the drying process of the olive pomace briquette were 92.09 and 7.09%, respectively. The results of the energy analysis indicated that drying olive pomace briquettes at higher temperatures, lower velocities, and a lower relative humidity of drying air had better energy efficiency.

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