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Scientific Research

The effect of ultrasound pretreatment at different powers and temperatures on the drying process of cornelian cherry

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ABSTRACT

In this research, the effect of ultrasound treatment at different powers and temperatures on the drying process of cornelian cherry by infrared dryer was investigated and modeled. The effect of the applied power by the ultrasonic device at three levels of 0, 75 and 150 W and the effect of the ultrasonic treatment temperature at three levels of 20, 40 and 60 °C on the mass transfer rate and the effective moisture diffusivity coefficient during the drying process of cornelian cherry were investigated. The results of this research showed that ultrasonic pretreatment before drying cornelian cherry by the infrared dryer, by creating microscopic channels on the product surface due to the cavitation phenomenon, makes it easier for moisture to exit from the product and thus reduces the drying time. By increasing the ultrasonic power from 0 to 150 W, the average drying time of cornelian cherry decreased from 73.2 minutes to 51.4 minutes. By increasing the treatment temperature from 20 to 60 °C, the average drying time of cornelian cherry decreased from 69.7 minutes to 55.7 minutes. The effect of power and time of ultrasound treatment on the effective moisture diffusivity coefficient changes of cornelian cherry was investigated and the results showed that with the increase in the power and temperature of the ultrasonic device, the values of this coefficient increase. By increasing the sonication power from 0 to 150 W, it was observed that the effective moisture diffusivity coefficient increased from 6.63×10^{-9} m^2s^{-1} to 10.11×10^{-9} m^2s^{-1}. The average effective moisture diffusivity coefficient of cornelian cherry treated at temperatures of 20, 40 and 60 °C were 7.26×10^{-9} m^2s^{-1}, 8.10×10^{-9} m^2s^{-1}, and 9.45×10^{-9} m^2s^{-1}, respectively. In order to investigate the drying kinetics of cornelian cherry, mathematical models were fitted to the experimental data. In modeling of cornelian cherry drying process, the Page's mathematical model with two parameters (k and n) was chosen as the best model due to the minimum error.

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1. Introduction

Cranberry fruit with scientific name (*Male horn* L) is a fruit whose tree grows naturally in the temperate regions of the Eastern Hemisphere, Peru and large areas of Europe, Asia and especially Iran. In Iran, Qazvin province is the pole of production of this product, and this fruit is also harvested in the northwestern provinces of the country. This fruit contains small amounts of glucose and sucrose and is rich in iron, calcium, folic acid, vitamins C, B_1، B_2 and E, flavonoids, oxalic acid and anthocyanin. This fruit is rich in antioxidants and has a high ability to fight cancer and has antibacterial, anti-allergic, cholesterol-lowering and anti-diabetic properties [1, 2].

Nowadays, due to the proof of the nutritional properties and usefulness of fruits on human health as well as the prevention of various diseases, attention and focus on the consumption of fruits and healthy products prepared from them has increased. One of the most important methods of processing vegetables and fruits is drying them, which facilitates transportation, increases storage capacity, and reduces microbial activity [3]. In a study, Ozgen (2015) investigated the drying process of cranberry fruit in a hot air dryer. The temperature of the dryer air and its speed in this research were considered in the ranges of 35 to 55 degrees Celsius and 1 to 1.5 m/s, respectively. The shortest drying time of this fruit (40 hours) was obtained when the air temperature was 55 degrees Celsius and the air speed was 1.5 m/s [4]. In another study, Kaya and Aydin (2010) investigated the drying kinetics of cranberry fruit in a hot air dryer. Experiments in a convective dryer on a laboratory scale under different drying conditions including temperatures of 25, 30, 40, 50 and 60 degrees Celsius, air speed of 0.3, 0.6 and 0.9 m/s and relative humidity values of 25, 40 , 55 and 70 percent, was done [5].

The frequency of the sound wave is the number of contractions and expansions (number of vibrations) in one second. The frequency range of 20 to 20,000 Hz is called sound, frequencies below that are called infrasound, and frequencies above that are called ultrasound or ultrasound (beyond the range of human hearing). The passage of sound waves through fluids causes their molecules to vibrate, cause contraction and expansion in them, and the formation of high-pressure (in the contraction phase) and low-pressure (in the expansion phase) points, and can cause cavitation in fluids. In the food industry, ultrasound waves have various applications. For example, this method can be used as a pretreatment before the drying process [6-8]. Ghorbani and Esmaili (2022) used ultrasonic pretreatment to dry blueberries using hot air. The results of this research showed that ultrasonic pretreatment has a statistically significant effect on the final thickness and by dispersing the waxy compounds on the surface of the cranberry skin and creating microscopic channels, it causes ease of mass transfer and reduces drying time [1]. Krohnke et al. (2021) investigated the effect of ultrasound on the kinetics of the osmotic dehydration process and drying of kiwifruit. Based on the results of this study, the use of ultrasonic waves reduced the drying time of kiwi [7].

One of the new methods of drying food is using an infrared dryer and an infrared lamp as a heat source. Infrared rays are part of the electromagnetic spectrum and are divided into three groups: near infrared, medium infrared and far infrared. Compared to other conventional heating methods, infrared radiation has several advantages and the quality of the dried product is higher. In this method, the process time is shorter and requires less energy consumption [3]. Huang et al. (2021) showed that moisture transfer kinetics using improved infrared radiation significantly reduced drying time and energy consumption [9]. In another study, Ding et al. (2015) investigated the improvement of shelf life of paddy and brown rice using infrared heating. The results of this study showed that infrared drying has no adverse effect on the quality of dried rice. Also, using an infrared dryer reduces the cost of processing and increases the shelf life of the final product [10]. Hosni et al. (2020) investigated the drying of sumac with different methods, including sun and shade, infrared and microwave, and confirmed that compared to

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traditional methods, the infrared dryer performs the drying operation in less time [11].

Investigating and using new methods such as infrared and ultrasound improves the appearance and quality of dried products. It is possible to reduce the drying time of agricultural products by using the mechanical nature of ultrasound waves (creating cavitation). In addition, it is expected that the drying time of cranberries using infrared rays will be shorter and will minimize the damage during the drying process. Therefore, in this research, the effect of ultrasound treatment power and temperature on the drying process of cranberry by infrared dryer is investigated and modeled.

2- Materials and methods

2-1- Preparation of blueberries

To carry out this research, fresh and ripe blueberries with an average diameter of 1 cm were obtained from Alamut city of Qazvin province and were kept in a freezer at -18 degrees Celsius until the beginning of the experiments. To apply each treatment, first the samples were defrosted at ambient temperature and then three blueberries were selected and placed in the ultrasound machine for 5 minutes for treatment.

2-2- Ultrasound treatment

To apply ultrasonic treatment on blueberries, using an ultrasonic bath device made by Becker company[1] (Iran) vCLEAN1-L6 model was used with a working frequency of 40 kHz and ultrasonic power of 75 and 150 watts. To apply temperature treatments, the temperature of the ultrasonic device was set to 20, 40 and 60 degrees Celsius. After the temperature of the bath reached the desired temperature, the blueberries were placed inside the machine and the ultrasound and temperature treatments were applied to them for 5 minutes.

2-3- infrared drying process

The application of the infrared method in the field of thermal processes of agricultural products has been the subject of many researchers' research in recent years, and more recent results and applications of this technology are presented in this field. In this research, an infrared dryer with a power of 250 watts was used to dry the treated blueberries, and the distance of the samples from the surface of the lamp was 10 cm. Weight changes of samples during drying every one minute by digital scale[2] It was recorded with an accuracy of ± 0.01 gram, which was placed under the dryer. The reduction of the moisture content of cranberries, on a dry basis, was investigated against the drying time of Rasam and the effect of different drying treatments on it.

2-4- Calculation Humidity ratio parameter

Humidity ratio parameter[3] (MR) can make the data obtained from the drying process uniform and more uniform. Having the initial moisture content of the product and reducing its weight, the moisture ratio parameter when the product is dried is calculated by equation 1 [12].

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

In this regard, MR: moisture ratio (dimensionless), M_t Moisture content on a dry basis at any time t (grams of water per gram of dry matter), M_0 Initial moisture content on dry basis and M_{It} is It is the equilibrium moisture content (grams of water per gram of dry matter). For long drying times, values of M_{It} isCompared to the values of M_{of}, M_t It is very small; Therefore, the equation of moisture ratio during drying can be simplified as equation 2, and there is no need to measure the equilibrium moisture to calculate the moisture ratio [13].

$$MR = \frac{M_t}{M_o}$$

5-2- Calculation of the effective penetration coefficient of moisture

Throughout the drying process, diffusion is the dominant phenomenon of moisture transfer from the center of the sample to the surface, so

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1. Ultrasonic laboratory bath , vCLEAN1-L6, Backer, Iran.

2. Digital balance, LutronGM-300p (Taiwan)

3. Moisture ratio (MR)

in this study, the mass transfer space was considered as a flat plate (blade) and moisture removal was calculated based on Fick's second law, according to Equation 3 [14].

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

In this regard, L is half the thickness of the sample (in meters), n is the number of terms considered from the equation, t is the drying time (s) and D_{eff} Effective penetration coefficient (m^2s^{-1}) Are. Usually, the first term of this series is considered and the above equation is simplified as equation 4 and the effective diffusion coefficient is obtained through this equation and slope calculation.

$$MR = \frac{m_t - m_e}{m_0 - m_e} = \frac{8}{\pi^2}\exp\left[\frac{-\pi^2 D_{eff} t}{4L^2}\right]$$

By taking the natural logarithm of the sides of equation 4, equation 5 is obtained:

$$\ln MR = Ln\frac{8}{\pi^2} + \left(-\frac{\pi^2 D_{eff} t}{4L^2}\right)$$

Then the effective diffusion coefficient of humidity through the slope of the natural logarithm of the humidity ratio of the experimental data (*Ln*MR) was calculated against drying time and using equation 6.

$$Slope = \frac{\pi^2 D_{eff}}{4L^2}$$

In this regard, Slope is the slope of the line.

6-2- Kinetic modeling

The principle of mathematical modeling of the drying process of agricultural and food products is to match mathematical equations to the drying process, which can adequately express the characteristics of the system. Also, by using mathematical models, it is possible to achieve a better understanding of the drying process as a function of various variables by spending less time and money.

In this study, in order to investigate the kinetics and predict the drying process of cranberries, kinetic modeling was done with the help of experimental data and using different experimental models of drying. Wang and Singh, Handson and Pabis, diffusion approximation, Page, Newton, Midilli and logarithmic equations [14] were selected and analyzed to model the drying process of cranberry and to choose the best kinetic model. In order to model the experimental data of drying and obtain the constants of the models, MATLAB software version R2012a was used.

2-7- Statistical analysis

This research was analyzed in a factorial format based on a completely random design and using SPSS version 21 software. Drying tests were performed in three repetitions and Duncan's multiple range test was used at the 95% probability level to compare the average of the observed responses. Excel (2007) program was also used to draw graphs.

3. Results and Discussion

3-1- Investigation of mass transfer kinetics

The results of analyzing the variance of ultrasound power and temperature on the drying time of cranberries are shown in Table 1. As can be seen in this table, the effect of independent variables of ultrasonic power and ultrasonic bath temperature is significant at the 5% level ($P<0.05$), but their mutual effects are not significant at the 5% level ($P<0.05$).

Table 1 Results of analysis of variance for drying time parameters of cornelian cherry.

Sources of changes	Degrees of freedom	Sum of squares	Mean square	P
Power	2	2141.6	1070.8	0.002
Temperature	2	908.7	454.4	0.042
Power × Temperature	4	60.6	15.1	0.971
Error	18	2150.0	119.4	
Total	26	5261.0		

Figure 1 shows the effect of ultrasonic power and ultrasonic bath temperature on the drying

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time of cranberries. As can be seen in this figure, with the increase of ultrasonic power and temperature of the ultrasonic bath, the drying time of the samples has decreased. The longest drying time was related to the control sample (81 minutes) and the lowest drying time was related to the sample treated with 150 watts of power and 60 degrees Celsius, and the average drying time for this treatment was 44 minutes. Ozgen (2015) found the drying time of cranberry fruit in a hot air dryer in the range of 40 hours (air temperature of 55 degrees Celsius and speed of 1.5 m/s) to 67 hours (air temperature of 35 degrees Celsius and speed of 0.1 m/s seconds) has reported [4].

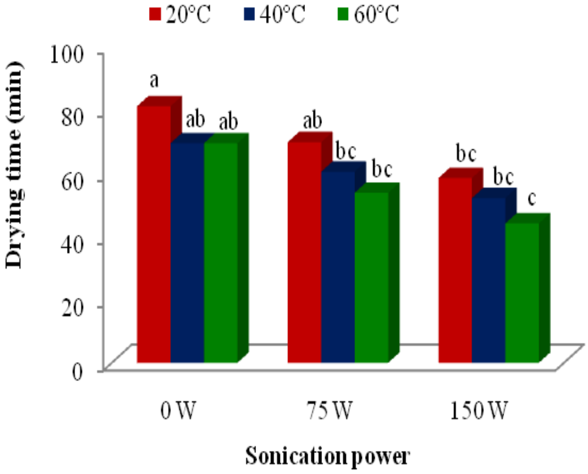

Fig 1 Average of cornelian cherry drying time at different ultrasound pretreatment conditions. Means with different superscripts differ significantly (P<0.05).

In a research, Salehi et al. (2022) investigated the effect of ultrasound power and time on the efficiency of the osmotic dehydration process of banana slices. Based on the results of this research, the application of ultrasound treatment increased the amount of moisture removed from banana slices and as a result reduced the time of the dehydration process [15].

2-3- The results of calculating the effective moisture penetration coefficient

Figure 2 shows the trend of changes in the natural logarithm of moisture ratio (LnMR) over time in samples treated with different ultrasonic powers. The slope of these lines was used to calculate the effective penetration coefficient. Figure 3 also shows the effect of changing the temperature of the ultrasonic bath on the trend of changes in the natural logarithm of the humidity ratio over time.

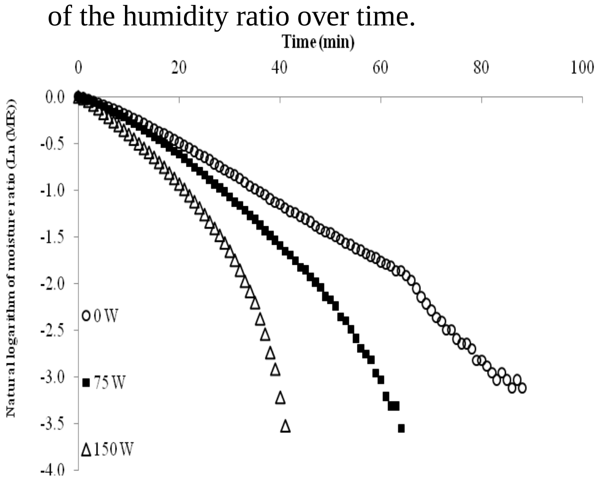

Fig 2 Variations of the natural logarithm of moisture ratio (Ln (MR)) values versus drying time of cornelian cherry at different sonication power (temperature=40°C).

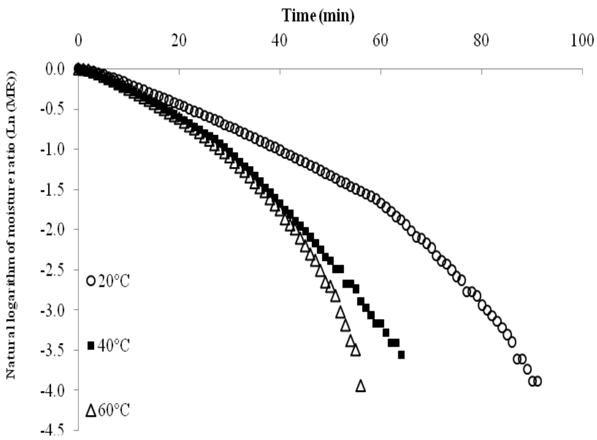

Fig 3 Variations of the natural logarithm of moisture ratio (Ln (MR)) values versus drying time of cornelian cherry at different temperature (sonication power=75W).

The use of ultrasound in the treatment of plant tissues can lead to the improvement of mass transfer kinetics. Examining the results of published articles on the combined use of different drying methods and ultrasonic waves indicates that the use of ultrasonic waves as a pretreatment before the drying process increases the speed of the drying process [6, 15-18]. As can be seen in Figure 4, with the increase of ultrasonic power and treatment temperature, the effective penetration coefficient of moisture has increased.

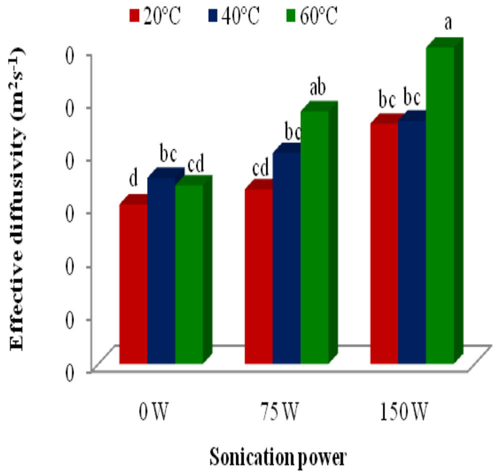

Fig 4 Effective moisture diffusivity values (D_{eff}) of cornelian cherry at different ultrasound pretreatment conditions.
Means with different superscripts differ significantly (P<0.05).

Ultrasonic pretreatment before drying blueberries with an infrared dryer disperses waxy compounds from the surface of the skin of the samples, and by creating microscopic channels on the surface of the product, it facilitates the removal of moisture from the product and, as a result, reduces the drying time. By increasing the ultrasonic power from 0 to 75 watts and from 75 to 150 watts, it was observed that the average humidity penetration coefficient of cranberry was from m^2s^{-1} 9-10x63/6 to m^2s^{-1} 9-10x07/8 and from m^2s^{-1} 9-10x07/8 to m^2s^{-1} 9-10 x 11.10 increased. By increasing the temperature of the ultrasound bath, the effect of ultrasound was intensified and the effective penetration coefficient of cranberry moisture increased. By increasing the temperature of the ultrasonic bath from 20 to 60 degrees Celsius, it was observed that the moisture penetration coefficient from m^2s^{-1} 9-10x26/7 to m^2s^{-1} 9-10 x 45.9 increased.

3-3- Choosing the best kinetic model

By calculating the amount of moisture ratio for all the studied treatments during the process of cranberry drying (using equation no. 2) and fitting the points obtained by drawing the moisture-time ratio diagrams, by means of Wang and Singh, Henson and Pabis models, diffusion approximation, Page, Newton, Midilli and logarithmic, the results for each model were examined (Table 2). In this table, the sum of squared errors[4] (SSE), coefficient of explanation (r) and root mean square error[5] (RMSE) and also the coefficients of these models are presented. The reason for using the root mean square error was that its dimension and scale were the same as the desired parameter. In Table 2, MR, humidity ratio, t time (min) and n, k, b, l, c and a are constants of the models. The best model should have the highest value of explanation coefficient and minimum error values. The results showed that the best model with the highest fit, according to the mentioned conditions, regarding the drying process of cranberries, is the Page model. Kaya and Aydin (2010) investigated the drying kinetics of cranberry fruit in a hot air dryer. These researchers used nonlinear regression analysis method to evaluate the constants of drying equations. The results of fitting the laboratory data with the existing models showed that the Henderson and Pabis, Lewis and binomial exponential models have a good agreement with the laboratory data related to the humidity of blueberries [5].

Table 2 The statistical parameters obtained in order to verify the fit of each mathematical model to the observed data during the cornelian cherry drying (sonication power=150W and temperature=20°C)

Model number	Model name	Model equation	Model constants	SSE	r	RMSE
1	Wang and Singh	$MR = 1 + at + bt^2$	a=-0.023 b=0.0001	0.018	0.998	0.016

4. Sum of squares due to error (SSE)

5. Root mean square error (RMSE)

2	Henderson and Pabis	$MR = a\exp(-kt)$	a=1.143 k=0.036	0.138	0.990	0.043
3	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	a=-15.84 k=0.064 b=0.947	0.021	0.998	0.017
4	Page	$MR = \exp(-kt^{n})$	k=0.007 n=1.414	0.012	0.999	0.012
5	Newton	$MR = \exp(-kt)$	k=0.032	0.279	0.980	0.060
6	Pony	$MR = a\exp(-kt^{n}) + bt$	a=0.119 k=-2.141 n=-0.036 b=-0.011	0.225	0.984	0.055
7	Logarithmic	$MR = a\exp(-kt) + c$	a=1.302 k=0.023 c=-0.233	0.015	0.998	0.014

Considering the lower error resulting from the fitting of the laboratory data with the Page model and the greater fit of this equation with the laboratory data, during the study of the drying kinetics of cranberry, the results of this model are reported in Table 3. Therefore, it is recommended to use this model to investigate the process of drying cranberries treated with ultrasound by an infrared dryer.

Table 3- The constants and coefficients of the accepted model (Page)

Sonication power (W)	Temperature (°C)	k	n	SSE	r	RMSE
0	20	0.0094	1.3937	0.0114	0.999	0.0115
0	40	0.0120	1.2710	0.0158	0.999	0.0125
0	60	0.0105	1.3130	0.0073	0.999	0.0093
75	20	0.0070	1.3927	0.0110	0.999	0.0110
75	40	0.0137	1.3103	0.0227	0.998	0.0174
75	60	0.0077	1.4533	0.0165	0.999	0.0160
150	20	0.0064	1.4827	0.0190	0.999	0.0164
150	40	0.0095	1.4190	0.0110	0.999	0.0138
10	60	0.0142	1.3653	0.0148	0.998	0.0172

In order to validate the proposed Page model, the values of changes in the humidity ratio predicted by the Page model and the values of the experimental humidity ratio obtained with an ultrasonic power of 150 watts and a temperature of 20 degrees Celsius are shown in Figure 5. As can be seen from this figure, there is a good agreement between the experimental moisture ratio and the one predicted by the model; Therefore, the proposed Page model is suitable for predicting changes in the moisture content of cranberry samples treated with ultrasound.

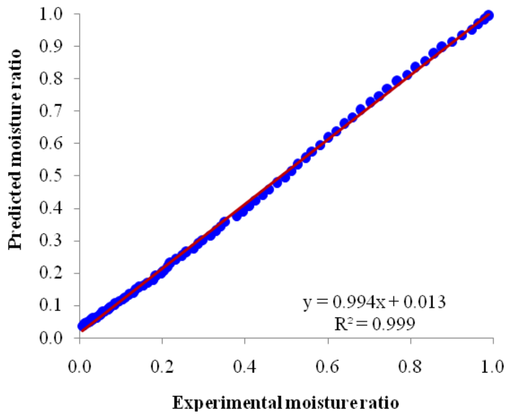

Fig 5 Comparison of fitted data by Page model with experimental results (sonication power=150W and temperature=20°C).

4 - Conclusion

Using traditional methods for drying fruits causes damage to the product and reduces their useful and health-giving properties. In

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this research, the effect of ultrasonic pretreatment at different temperatures on the drying kinetics of cranberries in an infrared laboratory dryer was studied. The results of this research showed that the ultrasonic pretreatment before drying the cranberries with an infrared dryer, by creating microscopic channels on the surface of the product due to the cavitation phenomenon, makes it easier for moisture to escape from the product and, as a result, reduces the drying time. The longest drying time (81 minutes) was related to the control sample that was not affected by ultrasound treatment, and the lowest drying time (44 minutes) was related to the sample treated with ultrasound with a power of 150 watts and at a temperature of 60 degrees Celsius. . With the increase in ultrasonic power, due to the increase in the intensity of the cavitation phenomenon and the increase in the mass transfer rate, the average effective diffusion coefficient of moisture from m^2s^{-1} $^{9-}$10x63/6 to m^2s^{-1} $^{9-}$10 x 11.10 increased. Different models were used to model the drying kinetics of cranberries, and Page's model was chosen as the best model due to the lowest amount of error.

5-Resources

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مقاله علمی_پژوهشی

اثر پیش‌تیمار فراصوت در توان‌ها و دماهای مختلف بر فرآیند خشک‌شدن زغال‌اخته

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پیش‌تیمار،

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زغال‌اخته،

مدل پیج.

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چکیده

در این پژوهش اثر تیماردهی با فراصوت (اولتراسوند) در توان‌ها و دماهای مختلف بر فرآیند خشک‌شدن زغال‌اخته توسط خشک‌کن فروسرخ بررسی و مدل‌سازی شد. تأثیر توان اعمال شده توسط دستگاه فراصوت در سه سطح ۰، ۷۵ و ۱۵۰ وات و اثر دمای تیماردهی با فراصوت در سه سطح ۲۰، ٤۰ و ٦۰ درجه سلسیوس بر سرعت انتقال جرم و ضریب نفوذ مؤثر رطوبت در طی فرآیند خشک شدن زغال‌اخته بررسی شد. نتایج این پژوهش نشان دادند که پیش‌تیمار فراصوت قبل از خشک‌کردن زغال‌اخته‌ها با خشک‌کن فروسرخ، با ایجاد کانال‌های میکروسکوپی در سطح محصول به دلیل پدیده کاویتاسیون، سبب سهولت خروج رطوبت از محصول و در نتیجه کاهش زمان خشک‌کردن می‌گردد. با افزایش توان فراصوت از ۰ به ۱۵۰ وات، میانگین زمان خشک شدن زغال‌اخته از ۷۳/۲ دقیقه به ۵۱/٤ دقیقه کاهش یافت. با افزایش دمای تیماردهی از ۲۰ به ٦۰ درجه سلسیوس نیز میانگین زمان خشک شدن زغال‌اخته از ٦۹/۷ دقیقه به ۵۵/۷ دقیقه کاهش یافت. اثر توان و زمان تیماردهی با فراصوت بر تغییرات ضریب نفوذ مؤثر رطوبت زغال‌اخته بررسی و نتایج نشان‌داد که با افزایش توان و دمای دستگاه فراصوت، مقادیر این ضریب افزایش می‌یابد. با افزایش توان فراصوت از ۰ به ۱۵۰ وات، مشاهده گردید که ضریب نفوذ مؤثر رطوبت از $6.63\times10^{-9}\ m^2s^{-1}$ به $10.11\times10^{-9}\ m^2s^{-1}$ افزایش یافت. میانگین ضریب نفوذ مؤثر رطوبت زغال‌اخته تیمار شده در دماهای ۲۰، ٤۰ و ٦۰ درجه سلسیوس به ترتیب برابر $7.26\times10^{-9}\ m^2s^{-1}$، $8.10\times10^{-9}\ m^2s^{-1}$ و $9.45\times10^{-9}\ m^2s^{-1}$ بود. جهت بررسی سینتیک خشک شدن زغال‌اخته، مدل‌های ریاضی بر داده‌های تجربی برازش داده شدند. در مدل‌سازی فرآیند خشک‌کردن زغال‌اخته، مدل ریاضی پیج با دو پارامتر (k و n) به دلیل حداقل خطا به‌عنوان بهترین مدل انتخاب شد.