Vibration effects on convective air-drying of bulk pistachios

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Abstract: The drying performance of bulk pistachios in a laboratory scale vibrated bed dryer was investigated under various operating conditions: inlet air temperature (50±2℃), air velocity (at 1.0 m/sec), frequency (0–60 Hz), amplitude (0.6 mm) and bed height (100 cm). The drying results showed that rising in drying efficiencies from 51.10% in 0 Hz to 76.90% in 50 Hz. Higher vibration intensity could not induce stronger efficiencies. The Logarithmic models provided the best fit of these drying results and further implied that the moisture transfer of pistachios was mainly controlled by internal diffusion. In comparison with the case of a conventional dryer, the air-vibro bed dryer showed improvement of drying characteristics, so the drying kinetics was largely dependent on the frequency of vibration.

Keywords: convective heat transfer, vibration bed, drying bulk pistachios

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1 Introduction

The yield of pistachio (Pistachio Vera l.) in central Iran has raised about 450,000 hectares and produces annually 420,000 tons of pistachios. Pistachio trees are estimated to be more than 80 million of 17 major varieties (Kouchakzadeh and Brati, 2012). The pistachios moisture at harvesting time is about 40%–50% (d.b.). However, for storage and consumption pistachios need to dry 5%–7%. Rate of drying pistachios in free air is slowly and needs two or three days that produce conditions in with fungus growth. So dryers are needed where pistachios in bulk expose hot air at temperatures 50–93℃ for 3–8 h. These dryers consume about ten million liters of mostly diesel fuel and natural gas firing each year (Kouchakzadeh, 2013).

One of the commercial pistachio dryers that were used commonly in Iran is the vertical cylindrical dryer (Figure 1). These dryers consist of centrifugal fan, heater, and cylindrical pore chamber with cone neck (Kouchakzadeh and Tavakoli, 2011).

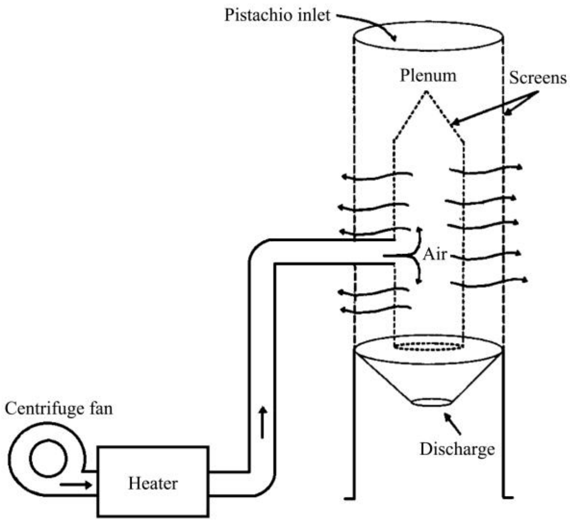

Figure 1 Schematic of vertical cylindrical pistachio dryer

The ventilation with hot air through the moist pistachios nuts immigrates moisture from nuts surface to air by humidity changes. This allows moisture migrating from nuts interior to external layer and exiting to air in the aeration. When hot air is forced through the bulk pistachios, it cannot flow well encircling of each nuts and must flow in cavities between particles (Kashaninejad et al, 2010). This makes a resistance to airflows and maybe reduces moisture transfer from nuts

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to air. Adding vibration to drying chamber may help to enhance the energy transfer. The motion of the vibrating support bed is assumed sinusoidal with amplitude x_0 and angular frequency ω, so that its displacement, x_p, is given by:

$$x_p = x_0 \sin(\omega t) \quad (1)$$

The utility of vibration beds are known in many industrial processing such as drying, heating, cooling, granulation and crystallization and so on. When a bed of particles is vertically vibrated at low vibration frequency, it stays in touch with the particles. At higher vibration frequency where the downwards acceleration of the vibrated bed surpass from the particles, an air gap between bed and particles is formed. Because of this condition, the aeration action throughout the particles is more easily than immobile bed (Janssen et al, 1998).

The specific objectives of this study were to determine the effect of mechanical vibration on drying kinetics of high moisture bulk pistachios.

2 Materials and methods

In this study, Akbari, one of the major varieties of Iranian pistachios was used for consideration of drying kinetics in mechanical vibration. The samples obtained from an orchard in Iran, Qom Province. The moist unshelled pistachios with the bulk density about 550 kg/m^3 were used in this research. The moisture contents of samples were determined by oven drying at temperature of 130℃ for 6 h according to a standard method ASABE (ASABE, 2006). The column with 95 cm depth of pistachios was placed on drying chamber of device dryer and every 30 min the samples were taken out while variation of weight of pistachio was recorded and moisture content was determined for each time. All experiments repeated three times.

2.1 Experimental procedure

The experimental setup is illustrated in Figure 2, consisting of a column bed made of stainless steel (50 cm diameter and 100 cm tall), an electric vibration table (model EVT-50, GeoTest Equipments, China) with 0.3–0.6 mm amplitude and vibration frequency 2860TPM , a vibration meter (model VB-8220 Lutron, Taiwan), a variable centrifugal fan, an electric heater. The vibration table was vertically driven by sinusoidal signals produced by a variable frequency drive (model iG5 0.37 kW, LG, Korea). Air velocity was controlled by adjusting the size of inlet and was kept at 1.0 m/sec with an accuracy of ±0.1 m/sec measured with an anemometer plus temperature meter (AM-4205A Lutron, Taiwan) flowed to air. A fixed air temperature of 50±2℃ was used during experiments. Drying experiments were carried out with vibration frequency 0, 10, 20, 30, 40, 50 and 60 Hz per 0.3 mm single amplitude (0.6 mm double amplitude). Sample weight was measured by a laboratory-weighing platform (Model AB204, Mettler-Toledo AG, Switzerland) and recorded at regular time intervals (30 min) and moisture content was determined for each time.

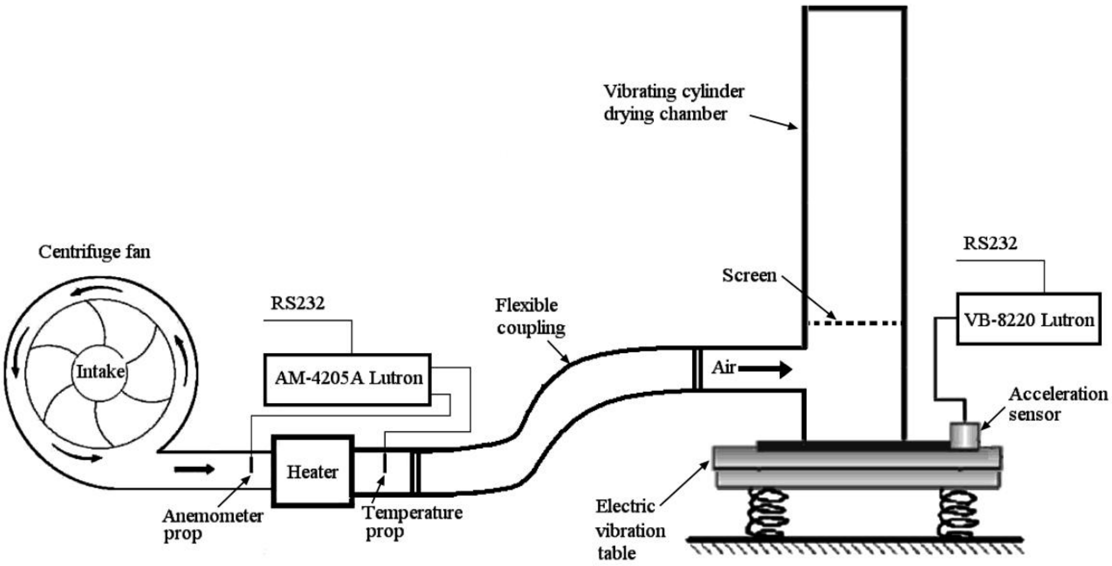

Figure 2 Schematic diagram of test apparatus

2.2 Mathematical modeling

Drying curves were fitted with six moisture ratio models that were tried by several researchers such as Midilli and Kucuk (2003), Kashaninejad et al (2007), Kouchakzadeh and Shafeei (2010) and Kouchakzadeh and Hagihgi (2011) for drying kinetic of pistachios. The mathematical models are represented in Table 1. These mathematical models have the most functional capacity to describe the drying behavior of biological materials (Kaleta et al, 2013). In all table equations $MR=M/M_0$ shows the ratio of present moisture to its initial moisture in any time, t is time, and other factors are the empirical values that were calculated by curve fitting technique by using software (Table Curve V.1.12, Jandel Scientific, Germany). The acceptability of models was determined by the Mean Relative Absolute Error (MRAE) according to Equations (2) to (4) as:

$$e_i = \frac{(MR_i - MR_i^c)}{MR_i^c} \quad (2)$$

$$E = \sum_{i=1}^{n} Abs(e_i) \quad (3)$$

$$MRAE(\%) = \frac{E}{n} \times 100 \quad (4)$$

where, MR_i is the experimental moisture ratio; MR_i^c calculated moisture ratio; e_i is the fractional error; E is the sum of absolute errors, and $MRAE$ is the mean relative absolute errors; n is number of observation.

Table 1 Mathematical models applied to drying curves

	Models	Name
1	$M_R = \exp(-kt)$	Newton
2	$M_R = \exp(-kt^n)$	Page
3	$M_R = a\exp(-kt)$	Henderson-Pabis
4	$M_R = a\exp(-kt) + c$	Logarithmic
5	$M_R = a\exp(-k_0 t) + b\exp(-k_1 t)$	Two term
6	$M_R = 1 + at + bt^2$	Wang and Sing

2.3 Drying efficiency

The drying efficiency was calculated as:

$$n_d = (1 - \frac{MR_p}{MR_i}) \times 100 \quad (5)$$

where: n_d is the drying efficiency in percentage; MR_p and MR_i is the present and initial moisture ratio in kg/kg.

3 Results and discussion

The values of present moisture on initial moisture in any time were shown in Figure 3. The experimented data (MR) were presented as a plot of MR vs. frequency (Hz) for 120, 240, 360 and 480 min aeration as illustrated in Figure 4. As shown in figure, drying time reduces with the increase in vibration frequency. If the drying chamber have not been vibrated, the moisture ratio of pistachios after 480 min aeration became 0.489 kg/kg, but in 10, 20, 30, 40, 50 and 60 Hz reduced to 0.463, 0.393, 0.292, 0.242, 0.231 and 0.237 kg/kg, respectively.

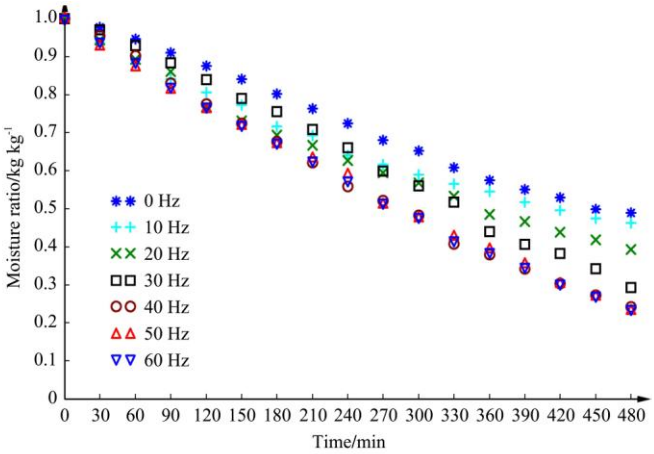

Figure 3 Variation of moisture ration vs. time on various frequencies

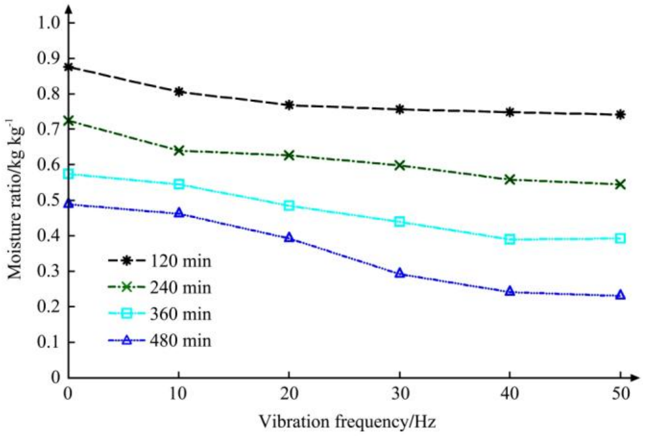

Figure 4 Variation of moisture ratio vs. vibration frequency for 120 to 480 min drying time

Maximum slope of MR vs. time were observed at 0.001624 in 40 Hz and minimum slope at 0.001099 in 20 Hz. It shows a negligible difference between 40, 50 and 60 Hz and may not be justified using the higher vibration frequencies. As illustrated in Figure 5 the drying efficiencies at 480 min drying time rises from 51.10% in 0 Hz to 76.90% in 50 Hz. Then it was observed that efficiency in 60 Hz is reduced to 76.35%. In comparison with the case of a conventional dryer in previous work that was 69.4% (Kouchakzadeh and Tavakoli, 2011), this exhibited improvement of drying characteristics.

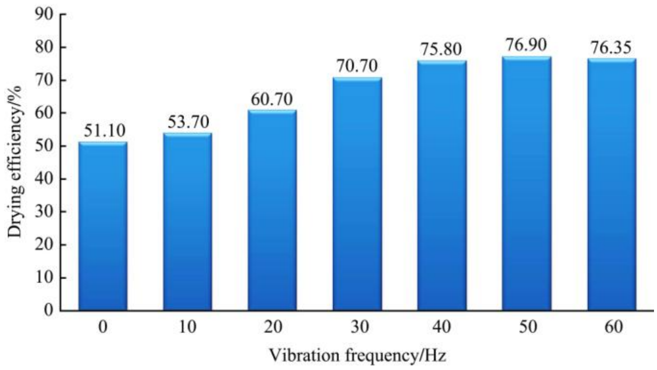

Figure 5 Drying efficiency in various vibration frequencies at 480 min drying time

The calculated values for all six models were presented in Table 2. For comparison of best model selection the *MRAE* were calculated in Table 3. As shown in table the Logarithmic models with lowest averages of *MRAE* 1.21% are the best-fitted models and Henderson Pabis models with highest averages of *MRAE* 5.54% are the worst.

Midilli and Kucuk (2003) reported the Logarithmic is the best model for prediction of behavior of thin layer drying of pistachio by using solar energy. Kashaninejad et al (2007) showed that the Page model was the most suitable for describing the drying behavior of the pistachio nuts by convective heating. Kouchakzadeh and Shafeei (2010) showed that the Page model was adapted for microwave–convective drying of pistachios. Kouchakzadeh and Ghobadi (2012) reported that the logarithmic model is the excellent model for ultrasonic assisted convective drying of pistachios. Kouchakzadeh and Hgihgi (2011) expressed the logarithmic model for infrared assisted vacuum drying of pistachios is the best and in combination of acoustic and solar energy, the page model was the most selected (Kouchakzadeh and Ghobadi, 2012).

Table 1 Parameters of calculated drying models

Vibration frequency, Hz		0	10	20	30	40	50	60
Newton	*k*	2.63e-3	1.84e-3	1.54e-3	1.65e-3	1.89e-3	1.24e-3	1.59e-3
Page	*k*	0.46e-3	2.15e-3	2.15e-3	2.25e-3	1.05e-3	2.35e-3	3.40e-3
	n	1.25	0.95	0.96	0.79	0.79	0.99	0.87
Henderson Pabis	*a*	0.95	0.91	0.93	0.49	0.90	0.87	0.98
	k	2.63e-3	1.99e-3	1.19e-3	1.64e-3	1.24e-3	1.94e-3	1.62e-3

Logarithmic	*a*	1.77	0.92	0.67	0.73	0.97	0.91	0.77
	k	1.21e-3	2.03e-3	2.01e-3	2.12e-3	3.25e-3	3.03e-3	2.27e-3
	c	-0.69	0.21	0.12	0.69	0.22	0.11	-1.23
Wang and Sing	*a*	-2.02e-3	-1.86e-3	-1.67e-3	-1.23e-3	-1.17e-3	-1.47e-3	-1.72e-3
	b	8.56e-7	1.33e-6	1.13e-6	1.11e-6	1.93e-6	1.30e-6	1.33e-6
Werma et al.	*a*	8.32	5.31	3.26	4.33	5.29	3.33	4.59
	k	4.74e-3	1.86-3	1.88-3	1.16-3	1.59-3	1.09-3	1.65e-3
	g	5.12e-3	1.76e-3	1.96e-3	1.58e-3	1.37e-3	1.17e-3	1.63e-3

Table 2 Mean relative absolute errors (*MRAE*)

	Models					
Vibration frequency, Hz	Newton	Page	Henderson Pabis	Logarithmic	Wang and Sing	Werma et al.
0	6.22	1.31	8.05	1.73	1.65	1.21
10	1.83	0.55	2.18	1.38	0.83	3.94
20	5.33	1.67	7.41	0.90	1.58	1.69
30	1.83	0.55	2.18	1.38	0.83	3.94
40	3.00	1.96	4.23	1.22	1.23	1.70
50	5.33	1.67	7.41	0.90	1.58	1.69
60	5.13	1.76	7.34	0.93	1.55	1.36
Average	4.10	1.35	5.54	1.21	1.32	2.22

4 Conclusions

In this paper, the convective drying processes of bulk pistachios in a vibrated bed were investigated. Seven vibrated frequency were characterized in the bed. The results showed that increasing in drying efficiencies from 51.10% in 0 Hz to 76.90% in 50 Hz. Higher vibration intensity could not induce stronger efficiencies. The Logarithmic drying models were adapted to data.

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