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Infrared / Convection Dryer Utilization for Drying of Pomegranate Peels

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ABSTRACT

The aim of this study investigated the effects of some various variables on drying a thin layer of pomegranate peels exposed to infrared and hot air. Three different levels of infrared power, namely: 150, 200 and 250 W and three different exposure distance "the distance between infrared heater and samples" of dying are 10, 15 and 20 cm with air temperature 40 ºC and air velocity 1.5 m/s were studied. Moisture ratio and drying time affected by infrared power and exposure distance, compatibility of experimental data to some drying models, effective diffusivity "D_{eff}", Specific energy consumption "SEC "and rehydration were also studied. The results show that the higher the infrared power and the lower exposure distance the lower the moisture ratio and the total drying time reduced, and it was found that the least drying time was 30 minutes with infrared power 250 W and exposure distance 10cm. Lewis model was best fitness to the experimental data with average R^2 0.9972. The maximum values of D_{eff} were recorded at highest infrared power 250 W. The rehydration ratios ranged between 0.80 to 2.42 under various dryin conditions.

Keywords: Infrared, Convection, Pomegranate, Peels.

INTRODUCTION

Pomegranate fruit (*Punica granatum* L.) followed to the Punicaceae family. It is relatively distributed around the world. Pomegranate fruit is consumed as juice and can used in food industry in the manufacture of jellies, concentrates, (Fawole and Opare 2013). The fruit is comprised of peels and arils (which contain juice and seeds/kernels) sacs. During juice processing, the peel is a major by-product and accounts for about 50% of whole fruit mass. The peel is rich in polyphenols including flavonoids, phenolic acids and tannins These bioactive compounds possess different biological activities such as scavenging reactive oxygen species (ROS), inhibiting oxidation and microbial growth and reducing the risk of chronic disease such as cancers and cardiovascular disorders (Mphahlele *et al.* 2019). Pomegranate peels contained 15.56% protein, 1.3 % fat, 5.24% crude fiber, 50.84 mg vitamin C per 100g, 10 mg/ 100g calcium, 12 mg/ 100g magnesium, 36 mg/100 g phosphorus, 0.35mg / 100 g zinc, 3 mg/100g sodium, 236 mg/100g potassium (Abdel-salam *et al.* 2018).The Pomegranate peels used in traditional medicine for treating diarrhea, dysentery, stomachache, and healing wounds., and antioxidant extract of pomegranate peel higher that of seeds in methanol (Doymaz 2011).Since the pomegranate fruit peel is highly susceptible to microbial contamination and rapid spoilage in its wet state, drying could serve as an alternative method of preservation. Drying is an ancient process used to preserve and prolong shelf life of various food products (Mphahlele *et al.* 2016). Drying is the most important process since it has a great effect on the quality of product. Traditionally, pomegranate is dried in the open sunlight. But the sun drying has the disadvantages of time consumption, contamination with dust and insects, and also weather dependent (Emam *et al.* 2007). In recent years, Infrared drying has many advantages such as the energy savings, lower drying time, high-quality dried products, intermittent energy source, easy control of the process parameters, uniform temperature distribution, and clean operational environment, as well as space savings(Riadh et.al. 2015). infrared radiation can improve the drying time and directly transfer heat to depth of the materials. (Bae *et. al.* 2010). The main objective of the present work is to develop infrared / convection dryer for drying pomegranate peels and study the effect of infrared power levels and exposure distance of samples to be dried to infrared emitters "Ed" on the pomegranate peels moisture ratio, , drying rate, effective moisture diffusivity. This study also aims to evaluating the compatibility of the thin layer data to some drying models, calculation the specific energy consumption and evaluation the rehydration as quality indicator.

MATERIALS AND METHODS

In the present study was to study the effect of three IR power levels 150, 200, and 250 W and three a distance between infrared heater and samples in the tray 10, 15, and 20 cm. at a constant air velocity of 1.0 m/s. A laboratory scale infrared-convective dryer was developed for the present study and experiments were carried out in Laboratory of Agricultural Product processing Engineering Department Faculty of Agricultural Engineering Al-Azhar Univ., Cairo, Egypt.

Materials

Ore material:

Pomegranate fruit were sourced from a local market in Cairo Egypt. Fresh pomegranate peel was cut in the dimension of 10 ± 0.5 mm (length), 10 ± 0.5 mm (width) and 5 mm ± 0.5 thicknesses was used with the help of stainless steel knife. The pomegranate peel kept in a refrigerator at 4°C prior to use before drying process.. The initial moisture content was 72.77 % w.b.

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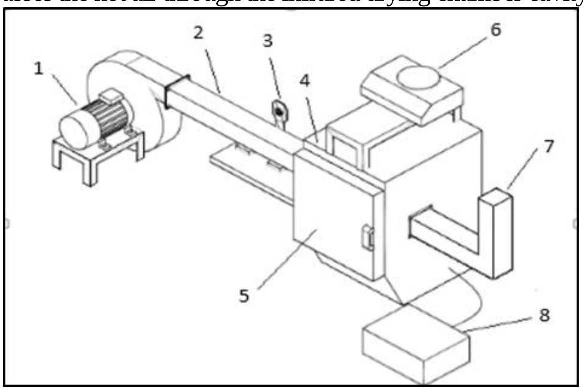
Infrared / convection dryer setup:

The infrared-convective dryer comprised of two components i.e. the hot air supply unit is connected on the drying chamber and having infrared heater (tube type). A schematic view of the experimental drier is shown in **Fig. 1.** The drying chamber of 400×300×300 mm were made from a plywood sheet of 8 mm thickness having a single door opening at the front. The inner sides of the chamber were covered with an aluminum foil. two openings for entering and exiting of hot air, dimensions of each opening. An infrared heater (tube type) of 400 W having length of 250 mm was fitted on the top inside surface of the drying chambers. It is controlled in IR power levels using electronic circuit (Arduino uno) by changing the intensity of the electrical current. A sample tray of woven wire mesh having dimension of 300×200 mm was placed beneath the infrared heater in a way that a distance of 10,15, and 20 cm was maintained between infrared heater and pomegranate samples in the tray. The hot air supply unit was a small air blower of 0.3 kW, 220 V, made in China, was used to supply the hot air flow rate. This blower was connected to the infrared drying chamber by means of housing with dimensions of 600 mm length, 100 mm width, 100 mm high made of galvanized iron sheet of 0.6 mm thickness and insulated from the outside by glass wool with thickness of 30 mm to prevent heat loss. The electrical heater of 2 kW maximum was fixed inside the housing to heat the drying air. Controlling the inlet air temperature of the infrared drying chamber was justified by a gas type thermostat. of the following specifications: Made in: Italy. Model: TUF – DF 09. The housing is connected to PVC tube diameter of 50 mm, insulated also by glass wool of thickness 30 mm. This tube passes the hot air through the infrared drying chamber cavity.



(1) Air blower	**(2) Air heater**
(3) Thermostat	**(4) drying chamber**
(5)door of drying chamber	**(6) A digital electric balance**
(7) chimney	**(8) electronic circuit (Arduino uno)**

Fig. 1. Isometric of infrared-convective dryer setup.

Thermostat:

Drying air temperature was controlled using thermostat made in Germany, accuracy 1ºC. This thermostat has been connected with the circuit of the air heater.

Turbo meter:

A turbo meter was used for measuring of the drying air speed. It is manufactured in U.S.A. by Davis instruments, measuring range of (0 – 44.8) m/s.

Electrical escapement:

Initial and final weights and weight changes during drying process of each sample were measured by A digital electric balance throughout the drying experiment measured the mass of the pomegranate at an interval of 10 min during experimentation.

Methods:

The initial moisture content of samples:

The initial moisture contents of the pomegranate (m) are evaluated by oven dried at 105 ºC (±1) for 24 hours. Is determined as follows . According to the ASAE standards (1994).

$$m = \frac{W_m}{W_m + W_d} \times 100 \quad (w.b\,\%) \quad \rightarrow (1)$$

Where:

***"W_m"* mass of moisture in sample (g),**
***"W_d"* mass of bone-dry material (g).**

Moisture content of sample during drying:

Moisture content (mt), (wet basis %):

The moisture content, wet basis % is determined as follows:

$$m_t = \frac{B - A\,(1 - m_i\,)}{B} \qquad \rightarrow (2)$$

Where

***"A"* is the initial mass of fresh sample (g),**
***"B"* mass of sample at any time (g) and m_i initial moisture content, w.b. %.**

Moisture content (Mt), (dry basis %):

The moisture content, dry basis % is determined as follows:

$$M_t = \frac{B}{A}\,(1 + M_i) - 1 \quad \rightarrow (3)$$

Where

"*Mi*" initial moisture content, (d.b. %).

Moisture ratio (MR):

Moisture ratio (MR) of pomegranate peels during drying was calculated using

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \rightarrow (4)$$

Where

***"M_t"* represents moisture content at any time (d.b. %),**
***"M_e"* equilibrium moisture content (d.b. %) .**

Drying rate. (DR):

The drying rate is determined as follows:

$$DR = \frac{MC_i - MC_f}{t} \quad \rightarrow (5)$$

Where:

***"MC_i"* : Initial moisture content of the product %;**
***"MC_f"*: Final moisture content of the product %; and *"t"* Elapsed time of drying (min.).**

Fitting of drying data to some thin layer drying models:

The moisture content data observed at the drying experiments were converted into the MR (moisture ratio) and fitted to the 8 models listed in table (1).

Table 1. Some mathematical models of drying applied to the drying curves of pomegranate seeds.

NO	Name of model	Model	Reference
1	Lewis	MR= exp (-kt)	Roberts et al. (2008)
2	Weibull	$MR = \exp\left[-\left(\frac{t}{b}\right)^a\right]$	Corzo et al. (2008)
3	Logarithmic	MR=a exp (-kt)+c	Wang et al. (2007)
4	Midilli et al	MR = a exp (-kt^n) +bt	Al – Muhtasab et al. (2010)
5	Page	MR = exp (-kt^n)	Ojediran and Raji (2010)
6	Modified Page	MR = exp (-(kt)^n)	Vega et al (2007)
7	Handerson and Pabis	MR = a exp (-kt)	Erbay and Icier (2010)
8	Wang and Singh	MR = 1 + at + bt^2	Akpinar (2010)

Data were analyzed using SPSS 6 "Statistical Package for the Social Sciences" for selecting the best model to describe drying curves The fitting quality of the experimental data to all models was evaluated using the coefficient of determination (R^2), reduced chi-square (χ^2), root mean square error (RMSE). and modeling efficiency (EF), These parameters were calculated from the following formulas:

$$R^2 = 1 - \frac{\sum_1^N \left(MR_{exp,i} - MR_{pre,i}\right)^2}{\frac{1}{N}\sum_1^N \left(MR_{exp,i}\right)^2} \rightarrow (6)$$

$$X^2 = \frac{\sum_{i=1}^N \left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - Z} \rightarrow (7)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^N \left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{\frac{1}{2}} \rightarrow (8)$$

$$EF = \frac{\sum_{i=1}^N \left(MR_{exp,i} - MR_{pre,ave}\right)^2 - \sum_{i=1}^N \left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^N \left(MR_{exp,i} - MR_{pre,ave}\right)^2} \rightarrow (9)$$

Where:

$MR_{exp,i}$ and $MR_{pre,i}$ are experimental and predicted dimensionless moisture ratios, respectively; N and Z represent the number of observations and constants, respectively. The best model describing the drying characteristics of samples was chosen as the one with the highest R^2, the least χ^2 and RMSE

Effective moisture diffusivity:

In drying, diffusivity is used to indicate the flow of moisture within the material. In the falling rate period of drying, moisture transfer occurs mainly by molecular diffusion. Moisture diffusivity of the foods is influenced mainly by moisture content and also by their temperature.

Fick's second law of diffusion is often used to describe a moisture diffusion process (Crank, 1975):

$$\frac{\partial m}{\partial \phi} = D_{eff} \cdot \nabla^2 m_{lo} \rightarrow (10)$$

Where

m_{lo} is the local moisture content (dry basis), ϕ time (s) and D_{eff} effective moisture diffusivity (m^2/s).

In most situations, the food product is assumed as:

Moisture is initially uniformly distributed throughout the mass of sample, mass transfer is symmetric with respect to the center, surface moisture content of sample instantaneously reaches equilibrium with the condition of surrounding air, resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample, mass transfer is by diffusion only and diffusion coefficient is constant and shrinkage is negligible.

The solution of Fick's equation for an infinite slab is as follows:

$$MR = \frac{M_t - M_e}{M_i - M_e} = \frac{8}{\pi^2}\exp\left(-\pi^2 . F_o\right) \rightarrow (11)$$

Where:

F_o Fourier number, $Fo = \frac{D_{eff} \cdot \phi}{L_{th}^2}$

L_{th} is the half-thickness of slab (m).

The previous equation can be rewritten as:

$$MR = \frac{8}{\pi^2} \cdot \exp\left(-\pi^2 \cdot Fo\right) \rightarrow (12)$$

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \left(\pi^2 \cdot Fo\right) \rightarrow (13)$$

$$Fo = -0.101 \ln MR - 0.0213 \rightarrow (14)$$

The effective moisture diffusivity (D_{eff}) was calculated using equation (16) as:

$$D_{eff} = \frac{Fo}{\left(\frac{\phi}{L_{th}^2}\right)} = \frac{-0.101 \ln MR - 0.0213}{\left(\frac{\varphi}{L_{th}^2}\right)} \rightarrow (15)$$

Rehydration ratio:

Rehydration capacity is useful to determine how the dried product reacts with the moisture. The rehydration capacities of dried slices were evaluated by immersing 5g of dried samples in boiled distilled water at room temperature Samples were removed at regular time intervals (each 5 min.) and weighed until difference in successive weighing was insignificant. Rehydration ratio was calculated from the following equation (Tayel *et al.* 2012)

$$\mathbf{Rehydration\ ratio} = \frac{W_t - W_d}{W_d} \rightarrow (16)$$

Where

"w_t"is the mass of rehydration sample at any time (g) and "w_d"mass of dried sample (g).

The specific energy consumption (SEC):

The specific energy consumption to evaporate water of the Pomegranate pelees in this study was calculated by dividing the input energy consumption kW.h/$kg_{water\ removed}$ by the removed water "w_w" kg.

$$The\ energy\ consumption = (P_i \times t_t) + (P_a \times t_t) \rightarrow (17)$$

Where

"P_i"is the infrared power (kW), "t_t" total drying time (h) and "P_a" power of air heated (kW).

$$P_a = v \cdot a \cdot \rho \cdot C_p \cdot \Delta T \rightarrow (18)$$

Where

"v" is the air velocity (m/s),"a" sectional area of air inlet (m^2), "ρ" air density (kg/m^3) at drying temperature, "C_p"specific heat of air (kJ/kg.ºK) at drying temperature and "ΔT" temperature difference between inlet and outlet of air (ºK).

The removed water "w_w" was calculated by the following equation:

$$w_w = \frac{A(m_i - m_f)}{(100 - m_f)} \rightarrow (19)$$

Where

"m_i"is the initial moisture content, (w.b. %), "m_f" final moisture content, (w.b. %) and "A" initial mass of material (kg),

By dividing the energy consumption by the water removed,

$$SEC\ (kW \cdot h / kg_{water\ removed}) = \frac{\left[(P_i \times t_t) + (P_a \times t_t)\right] \times (100 - m_f)}{A(m_i - m_f)} \rightarrow (20)$$

RESULTS AND DISCUSSION

- **Evaluation of the effect of infrared powers and exposure distance for infrared emitters "E_d" on the pomegranate peels drying curves:**
- **Moisture ratio:**

Fig. (2) Shows the relationships of moisture ratio and drying time as affected by infrared power and exposure distance for infrared emitters during all drying experiments "Ed". It is clear that the higher the infrared power and the lower exposure distance the lower the moisture ratio and the total drying time reduced, and it was found that the least drying time was 30 minutes with infrared power 250 W and exposure distance 10cm, while the highest drying time was 100 minutes with infrared power 150 W and exposure distance 20 cm.

Drying rate:

The effect of changing the infrared power levels and exposure distances for infrared emitters on the drying rate (g $_{water}$/min.) is shown in table (2). It is clear that as the infrared power level increases and exposure distance decreases the average values of drying rate increases. The maximum values of the average values of drying rate 2.33, 1.37 and 1.14 g $_{water}$/min. were recorded at exposure distance 10, 15 and 20 cm with the highest infrared power 250 W, while the minimum values of the average values of drying rate 1.16, 0.85 and 0.68 g $_{water}$/min. were recorded at exposure distance 10, 15 and 20 cm with the lower infrared power 150 W.

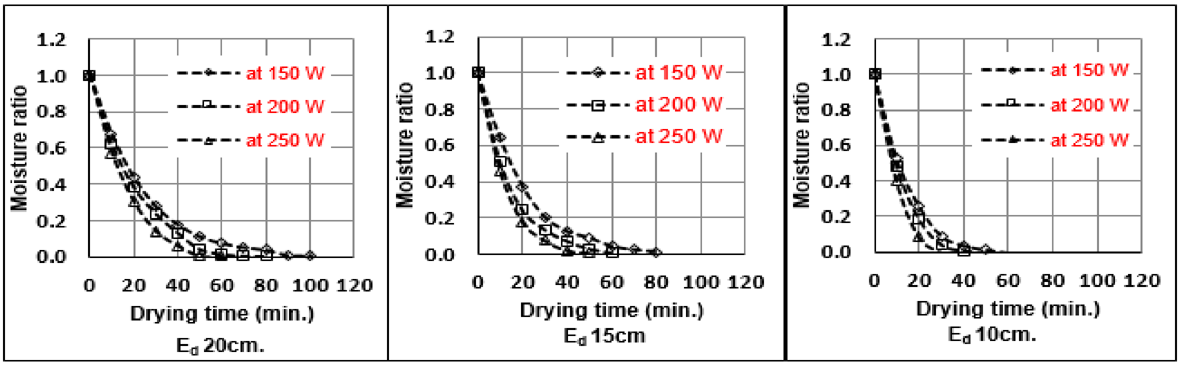


Fig. 2.Effect of Infrared power levels and exposure distances "E_d" on moisture ratio at air velocity 1.5 m/s.

Table 2. Average values of drying rate at different drying conditions in this study

		Average values of drying rate (g $_{water}$/min.)		
Infrared power (W)		**200**	**250**	**300**
exposure	10	1.16	1.40	2.33
distance	15	0.85	1.14	1.37
(cm)	20	0.68	0.86	1.14

Fitting of the drying curves with some drying model:

A wide set of thin layer drying models were examined in the present work. The selected models are identified in previous table (1).

Table (3) shows the constants of different models for drying process and its statistical analysis. The results showed that all models had good suitability to the experimental data under all drying conditions in this study. For all models, the statistical parameter estimations showed that R^2, EF, X^2 and RMSE values were ranged from 0.8644, 0.9634, 0.00003 and 0.00434 to 0.9998, 0.9999, 0.005199 and 0.060938 respectively, indicating a good fit. The highest averages of R^2 and EF values were 0.9972 and 0.9994 respectively, recorded with Lewis model, and then the Lewis model was best fitness to the experimental data.

Regression analysis was used to study the compatibility of the experimental data with Lewis model for all drying conditions studied of the form:

$$MR = e^{-kt}$$

Fig. (3) Shows that the best fit relations of the drying constant "k" as affected by infrared power "***P***" at the three different exposure distance were of the form:

$$k = ae^{bP}$$

The relation between parameter "***a***" and exposure distance "***d***" was as the following equation:

$$a = 0.224\,(d)^{-0.784}$$

It is clear that the parameter "***b***" doesn't change significantly and take the average value of 0.0043.

The general complete prediction equation from Lewis model for the moisture ratio takes the form:

$$MR = exp[-(0.224\,d^{-0.784}) \times (e^{0.0043\,P}) \times$$

R^2 = 0.9967t]

Fig 4. shows the predicted and observed moisture ratio.

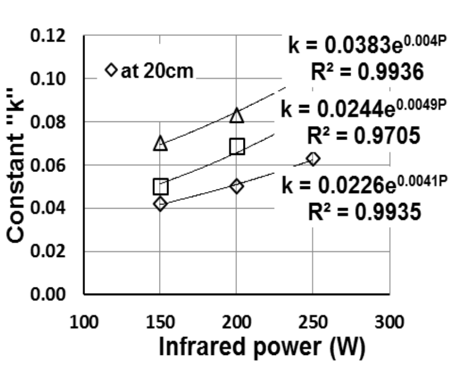


Fig.3.Relationship between constant "k" and infrared power level at different exposure distance.

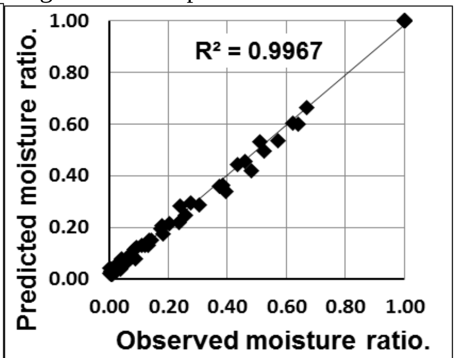


Fig. 4.Predicted and observed moisture ratio at different infrared power and exposure distance.

Effect of infrared power and exposure distance on moisture diffusivity:

Fig. (5) shows the relationships of the effective moisture diffusivity as affected by infrared powers and exposure distance "Ed". It is clear that moisture diffusivity increases as the moisture content decreases, and too it is clear that as the infrared power level increases and the exposure distance decreases the moisture diffusivity increases. Values of effective moisture diffusivity at exposure distance 20 cm ranged between $(0.12\times10^{-6} - 0.29\times10^{-6})$, $(0.17\times10^{-6} - 0.40\times10^{-6})$ and $(0.22\times10^{-6} – 0.56\times10^{-6})$ with infrared power 150, 200 and 250 W respectively, while Values at exposure distance 15 cm ranged between$(0.15\times10^{-6} - 0.34\times10^{-6})$, $(0.29\times10^{-6} - 0.52\times10^{-6})$ and $(0.36\times10^{-6} – 0.57\times10^{-6})$ with infrared power 150, 200 and 250 W respectively, and Values at exposure distance 10 cm ranged between$(0.27\times10^{-6} - 0.56\times10^{-6})$, $(0.33\times10^{-6} - 0.71\times10^{-6})$ and $(0.45\times10^{-6}– 1.12\times10^{-6})$ with infrared power 150, 200 and 250 W respectively.

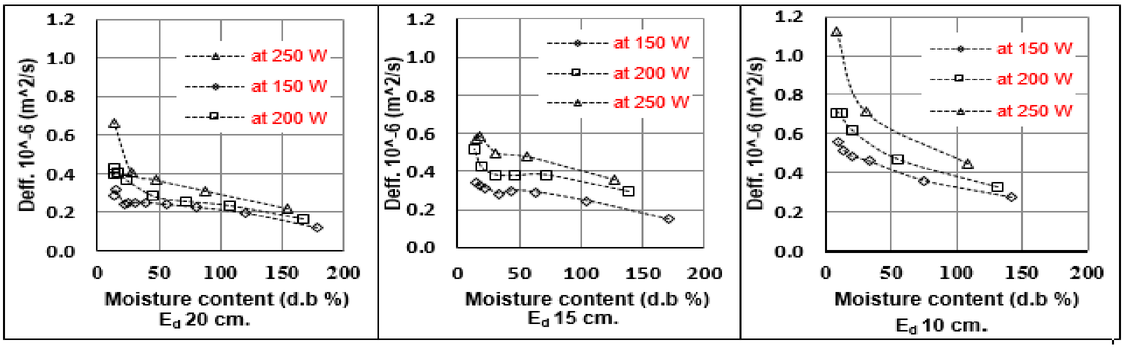


Fig. 5.Variation in effective moisture diffusivity "Deff" with moisture content at various infrared power and various exposure distance "Ed" at air velocity 1.5 m/s.

Table 3. The constants of different models for drying and its statistical analysis.

Models	Exposure dist. (cm)	Power levels(W)	Constant a	b	c	k	n	R^2	EF	X^2	RMSE
Lewis	20	200				0.042		0.9953	0.9993	0.000076	0.008328
		250				0.050		0.9975	0.9997	0.000503	0.021154
		300				0.063		0.9994	0.9998	0.000707	0.024617
	15	200				0.050		0.9992	0.9999	0.000242	0.014665
		250				0.069		0.9980	0.9995	0.000065	0.007469
		300				0.082		0.9947	0.9995	0.000221	0.013580
	10	200				0.070		0.9940	0.9992	0.000515	0.021017
		250				0.083		0.9966	0.9996	0.000990	0.028728
		300				0.104		0.9998	0.9978	0.001958	0.038322
Aevrage								0.9972	0.9994	0.0006	0.0198
Weibull	20	200	1.052	23.944				0.9983	0.9997	0.000031	0.005012
		250	1.107	20.378				0.9885	0.9978	0.000295	0.015142
		300	1.185	16.655				0.9960	0.9990	0.000163	0.010797
	15	200	1.099	20.293				0.9965	0.9993	0.000091	0.008393
		250	1.014	14.566				0.9980	0.9995	0.000078	0.007450
		300	1.113	12.510				0.9995	0.9998	0.000028	0.004338
	10	200	1.158	14.741				0.9968	0.9992	0.000125	0.009467
		250	1.286	12.815				0.9985	0.9996	0.000081	0.007366
		300	1.488	10.617				0.9992	0.9996	0.000117	0.007658
Aevrage								0.9968	0.9993	0.0001	0.0084
logarithmic	20	200	1.015		-0.009	0.041		0.9970	0.9995	0.000061	0.006665
		250	1.037		-0.035	0.046		0.9930	0.9987	0.000210	0.011831
		300	1.062		-0.057	0.054		0.9960	0.9990	0.000207	0.010868
	15	200	1.024		-0.014	0.049		0.9922	0.9985	0.000232	0.012434
		250	1.003		-0.002	0.069		0.9981	0.9995	0.000092	0.007262
		300	1.022		-0.019	0.078		0.9976	0.9993	0.000167	0.009147
	10	200	1.038		-0.034	0.065		0.9946	0.9987	0.000259	0.012160
		250	1.052		-0.046	0.074		0.9914	0.9977	0.000605	0.017386
		300	1.116		-0.114	0.081		0.9970	0.9986	0.000294	0.014839
Aevrage								0.9952	0.9988	0.0002	0.0114
Midilli et al	20	200	1.006	-0.00008430		0.042	1.100	0.9968	0.9995	0.000073	0.006827
		250	1.004	0.00000000		0.048	1.100	0.9915	0.9984	0.000305	0.013013
		300	1.006	0.00000000		0.058	1.100	0.9946	0.9986	0.000371	0.012614
	15	200	1.011	0.00000000		0.050	1.100	0.9919	0.9984	0.000292	0.012740
		250	1.001	-0.00004235		0.069	1.100	0.9981	0.9995	0.000120	0.007175
		300	1.003	0.00000000		0.080	1.100	0.9971	0.9992	0.000297	0.009957
	10	200	1.005	0.00000000		0.067	1.100	0.9933	0.9984	0.000432	0.013600
		250	1.007	0.00000000		0.078	1.100	0.9892	0.9971	0.001137	0.019471
		300	1.003	0.00000000		0.090	1.100	0.9961	0.9982	0.001133	0.016831
Aevrage								0.9943	0.9986	0.0005	0.0125

Continued:

Models	Exposure dist. (cm)	Power levels(W)	Constant a	b	c	k	n	R^2	EF	X^2	RMSE
Page	20	200				0.035	1.052	0.9983	0.9997	0.000031	0.005012
		250				0.036	1.107	0.9885	0.9978	0.000295	0.015142
		300				0.036	1.185	0.9960	0.9990	0.000163	0.013696
	15	200				0.037	1.099	0.9965	0.9993	0.000091	0.008393
		250				0.066	1.014	0.9980	0.9995	0.000078	0.007450
		300				0.060	1.113	0.9995	0.9998	0.000028	0.004338
	10	200				0.044	1.158	0.9968	0.9992	0.000125	0.009467
		250				0.038	1.286	0.9985	0.9996	0.000081	0.007366
		300				0.030	1.488	0.9992	0.9996	0.000117	0.007658
Aevrage								0.9968	0.9993	0.0001	0.0087
Modified Page	20	200				0.042	1.052	0.9983	0.9997	0.000031	0.005012
		250				0.490	1.107	0.9885	0.9978	0.000295	0.013696
		300				0.060	1.185	0.9960	0.9990	0.000163	0.010797
	15	200				0.049	1.099	0.9965	0.9993	0.000091	0.008393
		250				0.069	1.014	0.9980	0.9995	0.000078	0.007450
		300				0.080	1.113	0.9995	0.9998	0.000028	0.004338
	10	200				0.068	1.158	0.9968	0.9992	0.000125	0.009467
		250				0.078	1.286	0.9985	0.9996	0.000081	0.007366
		300				0.094	1.488	0.9992	0.9996	0.000117	0.007658
Aevrage								0.9868	0.9993	0.0001	0.0082
Handerson and Pabis	20	200	1.008			0.043		0.9958	0.9993	0.000075	0.007821
		250	1.011			0.051		0.9783	0.9959	0.000553	0.020747
		300	1.015			0.063		0.9806	0.9951	0.000802	0.023933
	15	200	1.014			0.051		0.9903	0.9981	0.000248	0.013888
		250	1.002			0.069		0.9980	0.9995	0.000078	0.007465
		300	1.005			0.083		0.9949	0.9986	0.000268	0.013357
	10	200	1.010			0.071		0.9846	0.9964	0.000594	0.020592
		250	1.012			0.084		0.9773	0.9938	0.001198	0.028262
		300	1.009			0.105		0.9801	0.9906	0.002898	0.038064
Aevrage								0.9867	0.9964	0.0007	0.0193
Wang and Singh	20	200	-0.027	0.000				0.8652	0.9634	0.004194	0.058581
		250	-0.033	0.000				0.9096	0.9829	0.002310	0.042385
		300	-0.042	0.000				0.9633	0.9908	0.001514	0.032881
	15	200	-0.033	0.000				0.8691	0.9745	0.003356	0.051093
		250	-0.044	0.000				0.8644	0.9665	0.005199	0.060938
		300	-0.053	0.000				0.9315	0.9808	0.003570	0.048788
	10	200	-0.045	0.000				0.9198	0.9812	0.003100	0.047054
		250	-0.053	0.000				0.9606	0.9893	0.002085	0.037282
		300	-0.072	0.000				0.9992	0.9996	0.000114	0.007564
Aevrage								0.9203	0.9810	0.0028	0.0430

Rehydration ratio:

The rehydration of pomegranate seeds dried by infrared dryer is affected by infrared power and exposure distance. Table (4) shows the relation between rehydration ratio and rehydration time at different infrared powers and different exposure distance. In all the cases, the amount of moisture absorbed increases with rehydration time and the rehydration stabilized in about 25 minutes.

Table 4. Rehydration ratio versus rehydration time at different infrared powers and different exposure distances.

Rehydration time (min.)	Rehydration ratio: exposure distance 10 cm, Infrared power levels (W). 150	200	250	exposure distance 15 cm, Infrared power levels (W). 150	200	250	exposure distance 20 cm, Infrared power levels (W). 150	200	250
5	0.83	0.82	0.80	0.88	0.88	0.83	0.91	0.89	0.84
10	1.54	1.42	1.37	1.62	1.51	1.45	1.69	1.59	1.49
15	1.97	1.82	1.75	2.04	1.89	1.82	2.11	1.97	1.93
20	2.26	2.04	1.86	2.35	2.11	1.98	2.34	2.20	2.10
25	2.27	2.05	1.87	2.36	2.12	2.00	2.38	2.22	2.14
30	2.27	2.06	1.88	2.36	2.12	2.02	2.42	2.23	2.15

The rehydration ratio under various infrared powers was in the range (0.80 – 2.27), (0.83 – 2.36) and (0.84 – 2.42) at exposure distance 10, 15 and 20 cm respectively.

Specific energy consumption "SEC":

Table (5) shows the Specific energy consumption "kW.h/$kg_{water\ removed}$" at the different drying condition. The minimum values of "SEC" 2.26 kW.h/$kg_{water\ removed}$ was recorded at infrared power 250 W and exposure distance 10 cm, while the maximum values was 5.20 kW.h/$kg_{water\ removed}$ at infrared power 150 W and exposure distance 20 cm.

Table 5. Specific energy consumption "SEC" at different infrared powers and different exposure distances.

Specific energy consumption (kW.h/$kg_{water\ removed}$)				
infrared power (W)		**150**	**200**	**250**
exposure distances (cm)	10	3.36	3.14	2.26
	15	3.98	3.79	3.75
	20	5.20	4.92	4.52

CONCLUSION

The main objective of the present work is to develop infrared / convection dryer for drying pomegranate peels and study the effect of infrared power levels and exposure distance of samples to be dried to infrared emitters "Ed" on the pomegranate peels moisture ratio, drying rate and effective moisture diffusivity. This study also aims to evaluating the compatibility of the thin layer data to some drying models, calculation the specific energy consumption and evaluation the rehydration as quality indicator. Three different levels of infrared power, namely: 150, 200 and 2500 W and three different exposure distance "E_d" of dying are 10, 15 and 20 cm with air temperature 40 ºC and air velocity 1.5 m/s were studied.

Results indicate the following:

- The higher the infrared power and the lower exposure distance the lower the moisture ratio and the total drying time reduced, and it was found that the least drying time was 30 minutes with infrared power 250 W and exposure distance 10cm.
- The maximum values of the average values of drying rate 2.33, 1.37 and 1.14 g $_{water}$/min. were recorded at exposure distance 10, 15 and 20 cm with the highest infrared power 250 W.
- The highest values for averages of R2 were 0.9972 recorded with Lewis model, and then the Lewis model was best fitness to the experimental data. The general complete prediction equation from Lewis model for the moisture ratio takes the form:

$\boldsymbol{MR = exp[-(0.224\, d^{-0.784}) \times (e^{0.0043\, P}) \times t]}$ **R^2 = 0.9967**

- The effective moisture diffusivity values increased with decrease in moisture content under all drying condition.
- The rehydration ratios ranged between 0.80 to 2.42 under various dryin conditions.
- The minimum values of "SEC" 2.26 kW.h/$kg_{water\ removed}$ was recorded at infrared power 250 W and exposure distance 10 cm

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استخدام مجفف أشعة تحت حمراء/ حمل لتجفيف قشور الرمان

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تهدف هذه الدراسة إلى تصنيع مجفف يعمل بالأشعة تحت الحمراء والحمل الحراري من خلال الهواء الساخن ليلائم تجفيف قشور الرمان فى طبقات رقيقة ومن ثم دراسة بعض العوامل المؤثرة على عملية التجفيف ومدى توافق النتائج مع بعض صيغ التجفيف الأخرى. وإمكانية إستنتاج نموذج رياضى يربط بين متغيرات الدراسة من خلال أفضل الصيغ. وتم دراسة ثلاث قدرات من الأشعة تحت الحمراء (150, 200, 250 وات) وثلاث مسافات بين العينات المراد تجفيفها ومصدر الأشعة (10, 15, 20 سم). ويمكن تلخيص أهم النتائج كما يلى: بزيادة قدرة الأشعة تحت الحمراء وتقليل المسافة بين العينات المراد تجفيفها ومصدر الأشعة إنخفضت نسبة الرطوبة والزمن الكلى للتجفيف. وكان أقل زمن للتجفيف 30 دقيقة عند قدرة الأشعة 250 وات ومسافة تعريض للأشعة 10سم. سجلت أعلى قيم لمتوسط معدل التجفيف 2,33 , 1,37 , 1,14 جرامماء /دقيقة عند مسافات تعريض للأشعة 10, 15, 20 سم على التوالى مع قدرة الأشعة 250 وات. أظهرت صيغة Lewis للتجفيف أفضل ملائمة للبيانات التجريبية حيث سُجل معها أعلى قيمة لمتوسط R^2 حيث كانت 0.9972 , وتم التوصل لنموذج رياضى من خلال هذه الصيغة يربط بين المتغيرات لهذه الدراسة حيث حقق الصورة:- $MR = exp[-(0.224\, d^{-0.784}) \times (e^{0.0043\, P}) \times t]$ $R^2 = 0.9967$ قيم الإنتشار الرطوبى إزدادت مع الإنخفاض فى المحتوى الرطوبى أثناء عملية التجفيف تحت ظروف التجفيف المختلفة لهذه الدراسة. تراوحت قيم التشرب ما بين (0,80 – 2,42) تحت الظروف المختلفة لهذه الدراسة. سجلت أقل قيمة لإستهلاك الطاقة النوعى (2,26 كيلو وات . ساعة /كجمماء مزال) عند قدرة الأشعة 250 وات ومسافة تعرض للأشعة 10 سم.