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Original Research Article

Development and Performance Evaluation of a Combined Infrared and Hot Air Dryer

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ABSTRACT

In this study, a laboratory scale infrared and hot air dryer was developed in which some parameters such as the temperature of drying chamber, input air temperature, air flow rate and distance from the infrared source was adjustable by operator. Drying of tomato thin layers was performed under various combinations of these parameters. Experimental results showed that drying time for temperatures of 60, 70 and 80 °C was 60, 75 and 116 minutes, respectively. Drying is directly related to the amount of operational infrared power. Moreover, drying time for two air velocities of 0.6 and 1.1 m s-1 was 109 and 95 minutes, respectively. Increasing the drying air velocity leaded to reduction of drying time because of an increasing in evaporation rate of moisture from the surface of the product at low speeds. Results showed that by increasing the distance of drying chamber from the infrared source, drying time will increase due to reduction of heat that transferred to the product. Minimum and maximum drying times were belonging to the temperatures of 80 and 60 °C, respectively. Also, the drying rate was directly related to the velocity and temperature of input air.

Key Words: Infrared, Hot Air Dryer, Tomato, Drying Time, Drying Rate

INTRODUCTION

Drying process in most industries has a considerable scientific and economic importance that its history goes back to the beginning of human civilization. This operation is designed to remove moisture from a product and preventing biological corruption and reach content of the material to equilibrium moisture. Drying is one of the most intensive energy-needing processes in various industries. This process in industrial scale with high thermal efficiency is important due to the high cost of energy and considering environmental problems and maintaining the quality of dried material (Mola *et al.*, 2010). The use of new technologies such as drying with combination of heat source convection and radiation seems necessary in order to increase the speed of drying (Afzal *et al.*, 1999; Honarvar *et al.*, 2009).

Several limitations of conventional dryers have been reported in recent years: high energy consumption, low efficiency, loss of product quality, lack of usability, expensive, large scale device and so on. Researchers show that using infrared dryers can solve problems related to conventional dryers. The use of infrared energy for food products has many advantages such as lower drying time, high energy efficiency, high quality of food products, uniform temperature and lower need to air flow through the product. Energy may be provided from different sources of electromagnetic radiation that their wavelength varies from the sun radiation to microwave radiation (0.2m – 2µm) (Keshavarz *et al.*, 2010). Heat radiation does not require physical environment for transfer and it is only the function of the radiative properties of the product and thermal source. Agricultural products have a coefficient of wave radiation absorption in the range of 0.7-0.9 m2 s-1. Therefore, many foods have the most absorption rate in the wavelength range of 2.5 to 3µm (Umesh *et al.*, 2004).

When electromagnetic waves strike the surface of a material, it will lead to product energy in the forms of electron motion, vibration and rotation of atoms and molecules. The increase of the internal temperature of materials is due to the red wave radiation that causes vibration of molecules and atoms. The friction which cause by this vibration generates heat and the internal temperature will be increased (Ginzburg, 1969; Meeso *et al.*, 2007; Honarvar *et al.*, 2009). This important advantage of infrared drying makes energy just heating up the material and does not have much impact on the surrounding environment. Therefore, the wastage of energy will be significantly reduced. As mentioned above, using of infrared source is one of the new methods which results improving the quality of product and drying rate. Although infrared drying is a new promising approach it

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cannot be a solution for all drying processes, because its penetrating power is limited. Therefore, it seems necessary to find new techniques that improve the performance of infrared dryers. Abe and Afzal (1997) introduced a combination of traditional removable and infrared radiation dryers as a successful technique for drying of food products. Combination of two convection (hot air) and radiation heat transfer mechanisms is important to increase the thermal efficiency of dryers. Therefore, with combination of these methods, it can be achieved the higher quality of final products and more energy efficiency.

The aim of this study was to design, develop and evaluate the performance of a combination of infrared and hot air driers.

MATERIALS AND METHODS

A laboratory scale infrared-convective dryer was developed in this study wherein, air temperature, humidity levels, temperature of the drying chamber and air velocity could be varied within the experimental range. Thin layer drying of tomato slices was done under various combinations of these process parameters.

Experimental dryer

The designed infrared-convective dryer comprised of two components i.e. a drying chamber which had a tube type infrared heater and a hot air supply unit. A schematic view of the experimental drier is shown in Figure 1.

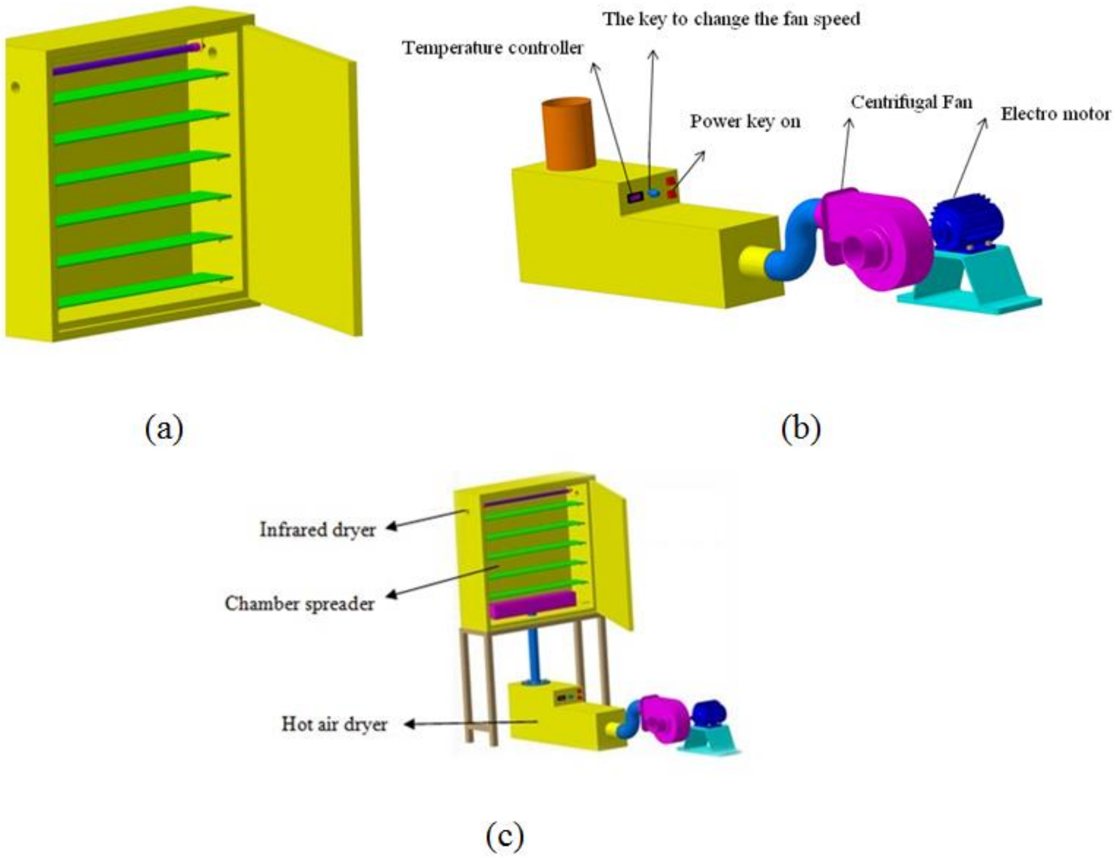


Figure 1. (a) schematic view of an infrared dryer (b) schematic view of a hot air dryer and (c) laboratory scale infrared and hot air dryer.

Infrared dryer

Figure 1 shows the infrared dryer with overall size of 1 m×1 m×0.3 m. This dryer was constructed like a cabinet because of its simple design and low cost and easy setup system. It is widely used in drying vegetables (Bottner and Sommerfeld, 2002). Main characteristics of the constructed dryer are represented in Table 1.

The efficiency of each infrared heating system mainly depends on the type of its heat source. Since the infrared energy will be converted to the heat when the material absorbs the radiation, it is necessary that a heat source will be selected that its range of radiation has the most rate of absorption (Afzal *et al.*, 1999). Study on the absorption of infrared radiation by the food products is shown that these materials have the strongest absorption rate in the wave range of 2.5 to 3 µm (Nowak and Lewicki, 2004). In this study, the wavelength of infrared source was selected from 2.4 to 3µm. The input power of the lamp (source) was 1.5 kW. To measure the temperature, a PT100 sensor (class B, DIN 60751, IST Co., Switzerland) and a controller (Autonics, TC4Y-14R, Korea) was used. A contactor (input 12V DC 1A and output 240V DC 15A) was used to cut off the flow of electricity. One of the parameters that affect the conditions of product drying is the amount of infrared radiation which is produced by the source. The intensity of this radiation actually is the output thermal energy of the infrared source. This intensity was adjusted by increasing or decreasing input voltage of the lamp using a dimmer. The electrical circuit used in the dryer is shown in Figure 2.

Table 1. Characteristics infrared drying.

Part	**Characteristics**
Overall dimensions (in meters)	1 (L) × 1 (W) × 0.3 (H)
Body Material	Steel 304
Infrared radiation source	Quartz infrared
The wavelength of infrared light	3 – 4.2 µm
Length of the radiation source	70 cm
Lamp input power	1.5 kw
Rubber Door	Silicon-resistant to 300°C

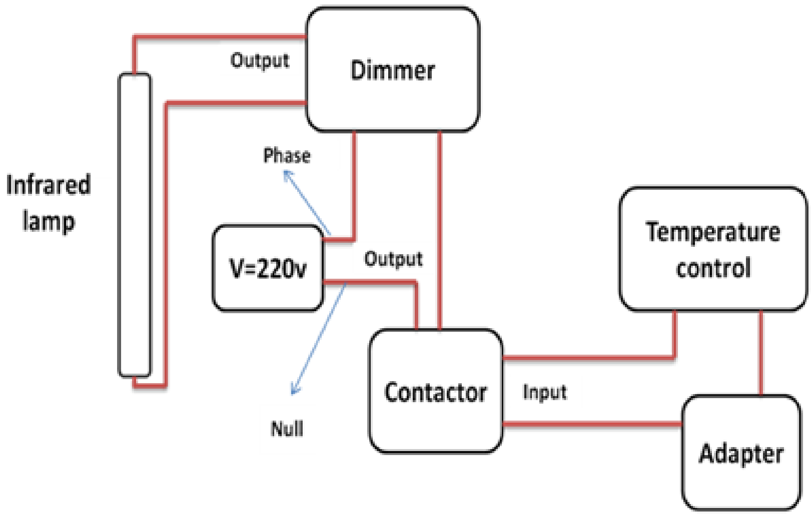


Figure 2. Electrical circuit used in the dryer.

Hot air dryers

Hot air dryer (Figure 1) which is used in this study includes an adjustable eccentricity fan, hot air channel, dryer chamber, tray containing samples and measurement systems and temperature control system. In this apparatus, changes of the fan speed and air was done manually. Heating system included an electric heater that was embedded in the channel. Temperature was controlled with a control system that worked with a microcontroller with precision of ±0.5 °C. Air velocity was measured using a digital speedometer with measurement range of 0 to 15ms^{-1}. Weighing system included a digital scale with precision of 0.01gr that was located out of the dryer chamber (Khani and khazaii 2008, Agha Masiha 2012). For uniform distribution of air in dryer, a distributor chamber was used (Figure 3). Distributor chamber was composed of a flow distributor plate and a mesh screen. Flow distributor plate was a plate that located just in front of the entrance of the air into the chamber distributor and its role in the drying chamber was even distributing of the air flow. Because the incoming air to the fan had a significant momentum, mesh plate eliminated the air turbulence before exiting of the air from this layer. Non-uniform output air velocity in different locations of the product tray disappeared using this plate (Kargar nemati, 2010).

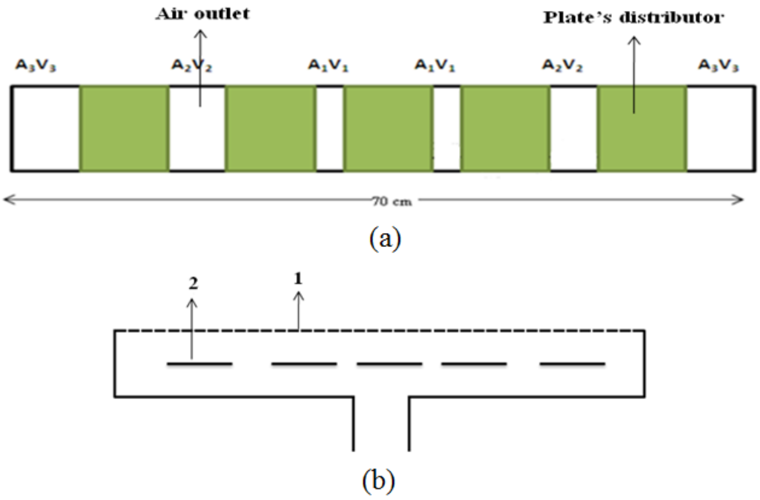


Figure 3. Hot air distributor (a) mesh plate (b) plate's distributor.

Performance evaluation of the dryer

Performance evaluation of the dryer was carried out with drying thin layer tomatoes in a research laboratory in College of Abouraihan (University of Tehran, Iran). Tomatoes that used for this study was purchased from a local store and to slow the chemical and physical changes was maintained in a refrigerator at 4 °C (Abano *et al.*, 2011). Before drying process, tomatoes were placed in a laboratory environment to reach the ambient temperature (25±1 °C). Then, tomatoes were washed and cut by two blades with 5mm distance to obtain 5mm tomato layers. Dryer launched 30 minutes before the experiment to reach a steady state. Drying temperature was set at appropriate value and 60±2 gr of the product was placed as a thin layer on an aluminum mesh with dimensions 10 cm×10 cm. Reducing the product moisture was measured by weighing samples at specified intervals using a digital scale with precision of 0.01 gr (Kern, EMB School balance, Germany) and the product was dried to reach the moisture equilibrium. To measure the air velocity, a blade wind gauge (Lutron, AM-4206, Taiwan) was used.

Moisture content

Humidity of a material can be calculated by dividing the amount of water weight of the material to the weight of wet matter or dry matter that are called moisture based on dry content and based on wet content, respectively (equations 1 and 2).

$$M_d = \frac{W_w - W_d}{W_d} \qquad (1)$$

$$M_w = \frac{W_w - W_d}{W_w} \qquad (2)$$

Where M_d is moisture of tomato sheets based on dry matter, M_w is moisture of tomato sheets based on wet matter, W_w is weight of samples during drying process and W_d is weight of the dried product (Abdelmotaleb *et al.* 2009, Ibrahim *et al.* 2011).

Ratio of moisture

Moisture content of Samples (*MR*) during the experiment was calculated from the equation 3.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (3)$$

Where M_0 is the initial moisture content of tomatoes (kg water/kg dry matter), M_e is equilibrium moisture content (kg water/kg dry matter) and M_t is the moisture content at any time (kg water/kg dry matter).

Considering that M_e is usually insignificant in comparison with M_0 and M_t, resulting error from its ignoring in this equation is very small and therefore, the equation can be transformed into a more simple form (Taheri Garavand *et al.*, 2011). The initial moisture content base on wet matter was calculated 95.6% using equation 2 by placing the samples in an oven for 24 hours at temperature of 105 °C.

RESULTS AND DISCUSSION

Effects of drying temperature

Figure 4(a) shows the effects of temperature on moisture ratio of tomato slices during the drying process. As shown in this figure, drying time for temperatures of 60, 70 and 80 °C was recorded 60, 75 and 116 minutes, respectively. Drying is directly proportional to the amount of infrared applied power. The vapor pressure is usually considered to be a function of both temperature and moisture content. The increase of infrared power might have caused a rapid increase in the temperature at surface of product, resulting an increase of the water vapor pressure inside the product and thus, increasing drying rates. The result is similar to results of the other researches (Sharma *et al.* 2005).

Effects of air velocity

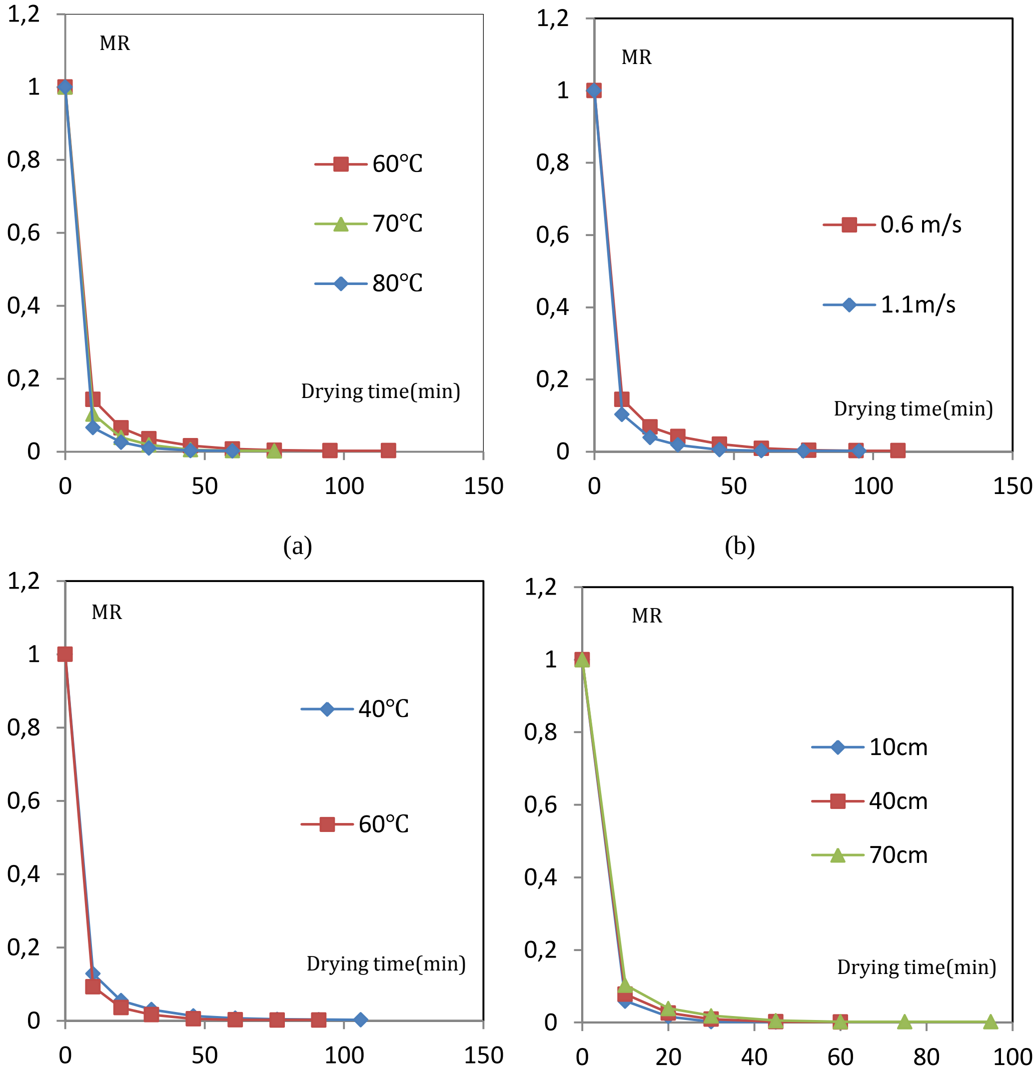
Effects of air velocity on drying process in the drier temperature of 70 °C, air temperature of 60 °C, slice thickness of 5mm and distance of 70 cm from the infrared source at 0.6 and 1.1 m s-1 air velocity are shown in figure 4(b). Drying time for two velocities of 0.6 and 1.1m s-1 was 109 and 95 minutes, respectively. Just as is clear, drying time was reduced by increasing the drying air velocity. This is due to the increase of evaporation rate of moisture at the surface of the product at low speeds. On the other hand, exceeding the air velocity from a certain value will increase the drying time. It is because of cooling effect and reducing the temperature at the product surface resulted by higher values of air velocity. Therefore, it reduces vapor pressure and ultimately reduces the amount of moisture losses. The result is similar to results of the other researches (Praveen Kumar *et al.,* 2005; Keshavarz *et al.,* 2010).

Effects of air temperature

Effects of air temperature on the drying process of tomato slices in drying temperature of 70 °C, thickness of 5mm, air velocity of 1.1 m s-1 and distance of 70 cm from the infrared source at temperatures 40 and 60 °C has been investigated and is shown in Figure 4(c). Results show that amount of reduced moisture increased by increasing the inlet air temperature and drying time was reduced. The result is similar to results of the other researches (Praveen Kumar *et al.,* 2005; Keshavarz *et al.,* 2010).

Effects of Distance from infrared source

In Figure 4(d), effects of product distance from infrared lamp in drying process of tomato slices is shown in drying temperature of 70 °C, air temperature of 60 °C, air velocity of 1.1 m s-1 for three distances of 10, 40 and 70cm from the infrared source. Drying time was recorded 45, 65 and 95 minutes, respectively. By increasing the distance between the product and infrared lamp, drying time will be increased due to the reduction of heat transfer to the product.



(a) (b)

(c) (d)

Figure 4. Effects of different dryer parameters on moisture ratio of tomato slices (a) dryer temperature, (b) air velocity, (c) air temperature and (d) distance between the product and infrared lamp.

CONCLUSIONS

In this study, a combination of infrared and hot air driers was designed and its performance is evaluated. By increasing the drying temperature, drying time was reduced due to increase of infrared power, so that the lowest and maximum drying time were belonged to the temperatures of 80 °C and 60 °C, respectively. The drying rate was directly related to the velocity and temperature of input air. By increasing the distance of product from the infrared source, drying time increased due to reduction of heat transferred to the product.

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