Designing, manufacturing and evaluating microwave –hot air combination drier

Amin Hazevazife[1*], Parviz Ahmadi Moghadam[2], A. Mohammad Nikbakht[3], Farough Sharifian[4]

[1]MSc in Mechanics of Agricultural Machinery, Urmia University, Iran
[2]Assistant professor of mechanic agriculture machinery urmia University, Iran
[3]Assistant professor of mechanic agriculture machinery urmia University, Iran
[4]Phd student in mechanic agriculture machinery, Urmia University, Iran
Amin.hazervazife@gmail.com

Abstract: In this paper, one microwave-hot air drier was designed and manufactured and then was evaluated. In the manufactured drier, one circuit was employed for feeding Magnetron lamp with nominal power of 1.3 kW and frequency of 2.45 GHz in order to produce microwaves. Hot air was produced using six 700 W heaters and a 175 rpm fan. The drier container volume was 30625 cm^3andhot airways blown into the container through its bottom face and microwaves were injected inside through its side face. This drier is capable of controlling microwaves power and temperature and flow rate of inlet air. Also during drying process, changes in mass and moisture of the product, inlet and outlet air temperature and total consumption power can be simultaneously measured. In order to evaluate operation of the manufactured drier, apple slices were dried up to their 20% moisture content using both microwaves and hot air. The results showed that increasing microwaves power causes the drying time to considerably reduce and drying rate to increases. On the other hand, increasing inlet air temperature had a significant effect on increasing drying rate while inlet air flow rate had a negligible effect on drying rate. Comparing operation of the device in two conditions indicated that comparing to hot air flow drying; drying rate can be increased up to approximately 10-fold by using microwaves.
[Amin Hazevazife, Parviz Ahmadi Moghadam, A. Mohammad Nikbakht, Farough Sharifian. **Designing, manufacturing and evaluating microwave –hot air combination drier**. *Life Sci J* 2012;9(3):630-637] (ISSN:1097-8135). http://www.lifesciencesite.com. 88

Key Words: Drier, Microwaves, hot air flow, drying time, drying rate, apple

Introduction

Drying is one of the most important processing operations of agricultural products which reduces speed of undesired chemical reactions such as oxidation and browning by decreasing moisture content of product and increases storage time by maintaining the appearance of products well (Goksu et al. 2204). Another advantage of drying products is easier use of dried foods in processes such as chopping, grinding and mixing. Also since foods weight and volume is reduced due to drying, their packaging, transportation and storage will be much easier (Li et al. 2011).

Human has used solar energy to dry agricultural products for many years. Despite advantages of solar energy in drying process, this method has its own disadvantages including lack of enough control on drying process, long drying time, occupation of high areas, high labor costs and insanitary dried products. These disadvantages provide reasons for development of industrial drying. The most common industrial drier is hot air flow drier in which hot air exposed to product causes moisture content to evaporate and product to dry. This dries have also some disadvantages such as singing product, high shrinkage in dried product, long drying time and high consumption energy (Das et al, 2003). Disadvantages of hot air flow driers and also needs for increasing efficiency of energy considering world energy challenges, encouraged researchers to find more efficient and appropriate methods for drying agricultural products. In recent years, many research shave been done on vacuum, freezing, infrared- hot air flow and microwave-hot air flow driers.

In microwave driers, microwave radiation is used for drying products. Microwave is an electromagnetic wave (combination of electric and magnetic fields) with a frequency in the range of 300 to 300000 MHz and a wavelength in the range of 1 m to 1 mm, respectively. These waves are capable of rotating bipolar molecules and due to high friction produced by changing polarity of molecules (for about several billion times per second), they produces heat in bipolar materials such as water (Kuchakzade and Shafer, 2010). Food and agricultural products since containing water are heated when exposed to microwaves and this heat cause evaporation of water molecules and drying the products.

In drying products using microwaves, in contrary to hot air flow method direction of heat and moisture movement is the same and is outwards. This increases moisture gradient in the product and accelerate mass transfer (Hu et al. 2006). On the other hand, using microwaves in drying process causes energy consumption to decrease and quality of dried products to increase (Andres et al., 2003). Moreover, since rotation of molecules is stopped when radiation of waves is removed, quick control of product temperature is feasible (Li et al, 2001).

Despite of mentioned advantages of using microwaves in drying process, this method can unevenly heat the product depending on thermal and dielectric properties of the product (Abbasisouraki and mowla, 2008). Also because of fast mass transferring this method, removal of emerging moisture from product is difficult and this result in condensation of steam inside the container (sharmaa et al., 2009). To overcome this difficulty combinedmicrowaves- hot air flow drying, pulsed microwaves and also combined microwave –vacuum drying can be used in drying process (Gunasekaran, 1999).

Despite abundant performed researches on designing and manufacturing driers and also drying agricultural products by different methods including design and manufacture of solar driers (Gatea, 2010), designing a solar drier for date (Ampratwum, 1998), kinetics of drying strawberry by hot air flow (Doymaz, 2008), kinetics of drying tomatoe by microwaves (Al-Harahsheh et al., 2009), drying carrot by combination of microwaves and halogen lamp (Sumnu et al, 2005) and drying apple and mushroom by combination of microwaves and hot air flow (Funebo and ohlsson, 1998 and Andres et al., 2004), yet sufficient information about manufacturing microwaves-hot air flow combination driers has not been available for researchers. The main purpose of this research is designing, manufacturing and evaluating one combined microwaves- hot air flow drier. For evaluating this device, apple fruit was dried separately under hot air flow and microwaves and drying parameters of product such as drying time, moisture ratio and drying rate were studied.

Materials and Methods

Design and manufacture of the device

The manufactured drier (Figure 1) has a microwave generator, inlet and outlet hot air flow channels, product container and device control board.

One Magnetron lamp with nominal power of 1.3 kW and frequency of 2.45 GHz was used in the drier for producing microwaves (Figure 2). Magnetron lamp which actually acts as an electron accelerator is fed by a high voltage circuit (Figure 3). Designed circuit consists of one transformer with voltage gain of 10 and also an inductive-capacitive circuit with voltage gain of 2through which 220 volts electrical current passes and the voltage rises to about 4500 volts which is threshold voltage of magnetron lamp. Since some heat is produced during operation of magnetron lamp, one fan is used to cool it down. Also because of using hot air flow in this drier and proximity of high voltage circuit to product container through which hot air is flowed, two other fans is used for cooling the circuit.

Figure1. A schematic of manufactured drier

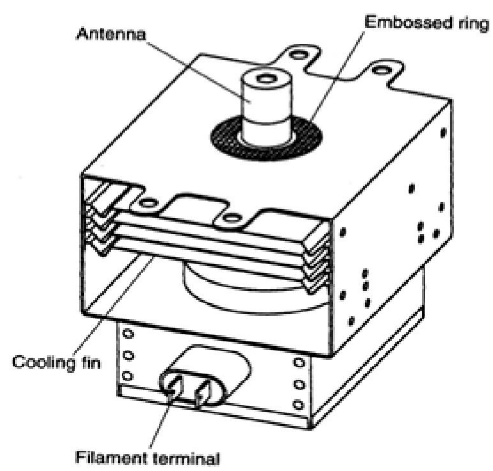

Figure 2.Schematic drawing of a magnetron lamp.

In order to adjust microwave generator, one control board is used by which magnetron lamp operation time and microwaves applied power can be controlled (Figure 4).

Product container (Figure 5) corresponding to employed magnetron lamp in the drier was designed as a rectangular cube with dimensions (38cm×35cm×22 cm) .

Since microwaves cannot pass through metals, product container was made of galvanized plate. Also because of polarity of metal molecules and therefore, being sensitive to microwaves, internal wall of container was coated by paint. On the other hand, product tray was perforated in order that hot air can easily pass on the product (Figure 5).

Figure 3.A schematic of high voltage circuits.

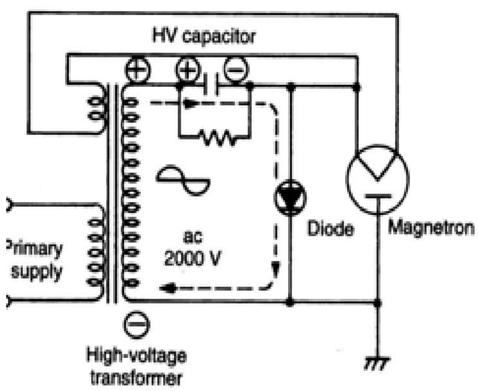

Figure 4.Control board of microwave generator

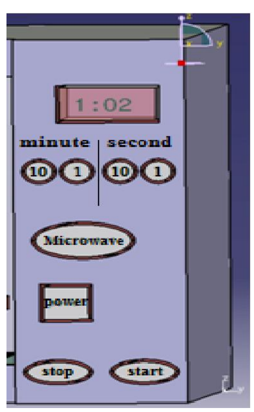

Figure 5. Container and perforated tray of product

For simultaneous measurement of product mass during drying process at desired time intervals, one load cell (sewhacnm, AB120) with accuracy to 1gr was used (Figure 6). Product tray was hanged from load cell by a connector that passes through a hole above the container. One inherent disadvantages of microwave is its inconsistent distribution inside the drier container. To overcome this problem, one engine was employed to rotate the product tray with constant speed to avoid heating some part of product too much.

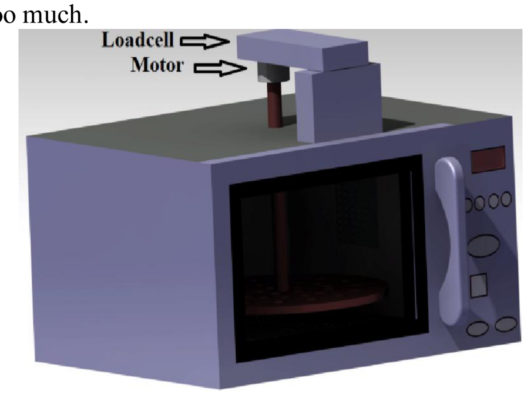

Figure 6. Load cell and the engine rotating product tray

In order to produce hot air flow, six 700 W heaters and one 1750 rpm fan were employed. Produced air flow was directed into product container by a channel (Figure 7). For controlling temperature of inlet air, a thermal sensor (PT100) inside air flow channel, a thermostat and contactor wereused. Consequently after measuring the temperature by the sensor and sending out a signal to thermostat which is adjusted at a desired temperature, a signal based on which the contactor decides to switch on or off the electric current is sent to contractor.

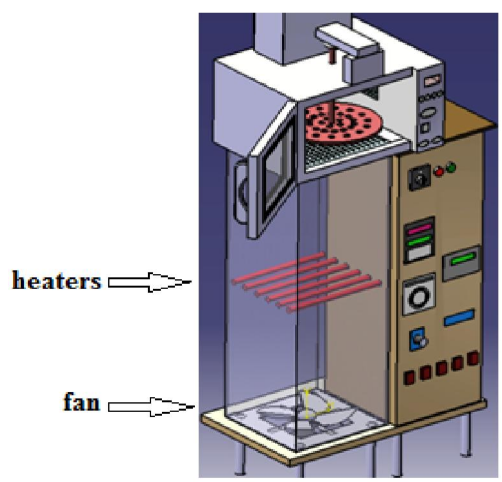

Figure 7. Hot air flow channel, heaters and fan

In order to prevent turbulence in inlet air and outgoing of microwaves and to make air flow uniform, one perforated plate with 2mm diameter holes was used at the bottom of product container (Figure 8). One dimmer was employed to change electric current into fan. Changing electric current of fan corresponding to different levels of air velocity (0.5, 1, 1.5, 2 m/s) rpm was also changed. Mentioned air velocities were measured using an anemometer located inside the air flow channel. It is noteworthy that external surface of the channel was insulated by fiberglass to prevent heat exchange between environment and air flow channel.

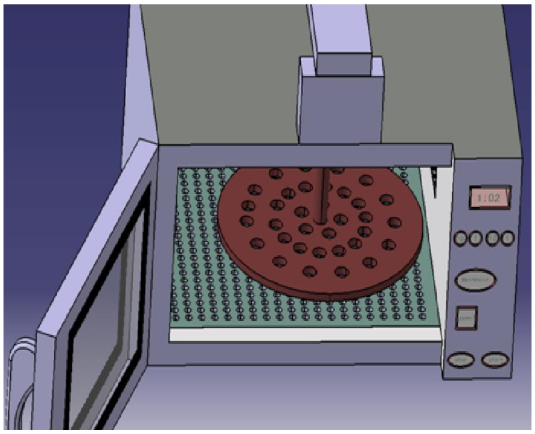

Figure 8. Perforated plate at the bottom of product container

Air which is flowed into the container should be removed after heating the product; therefore one channel is embedded at the top of container allowing air flow to outgo (figure 9). Inside this channel a moisture and temperature sensor (SHT75) is placed for measuring simultaneously the temperature and relative moisture of outlet air.

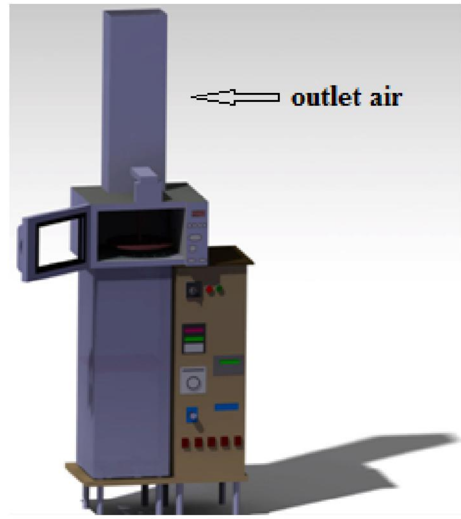

Figure 9. Outlet air flow channel

This drier is provided with a control board on which there are on and off switches of heaters, microwave, cooling fans and inlet air flow fan. Also inlet air temperature monitor and controller, product mass monitor and outlet air moisture and temperature monitor which simultaneously show the measured values during drying process are installed on this board. Product mass monitor and outlet air moisture and temperature monitor are connected to computer by a data logger and at the same time measured data are transferred to the computer.

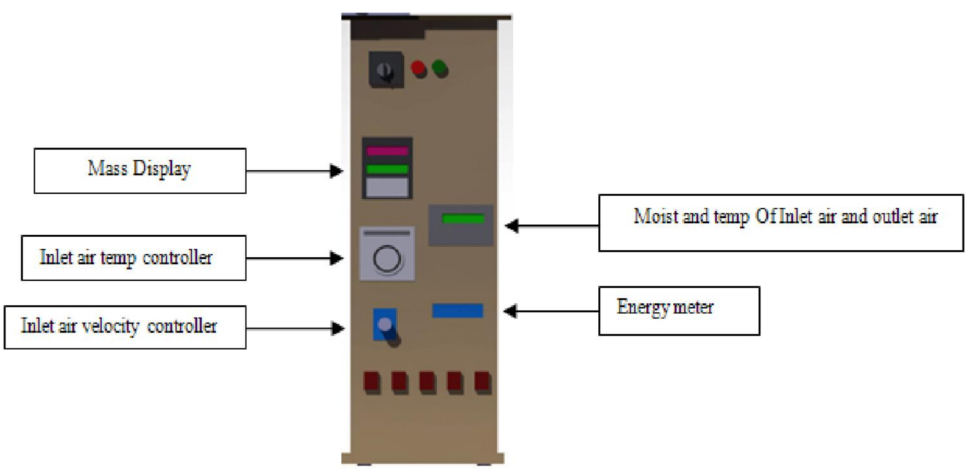

Figure 10. The drier control board and its elements

Preparing samples for evaluating the devise

For evaluating operation of manufactured drier, slices of golden delicious apple were used in experiments. Fruits were gathered from an orchard in Azarbayejan gharbi and transferred to a refrigerating room. Before the experiments, initial moisture of the product was calculated according to standard (AOAC, 1980) by a vacuum oven having fan and it was found to be 74.82 percent. Initially fruit peels were removed by a sharp knife and then 4mm thick cylindrical slices were prepared using a slicer and a specific mass of fruit were put on the product tray.

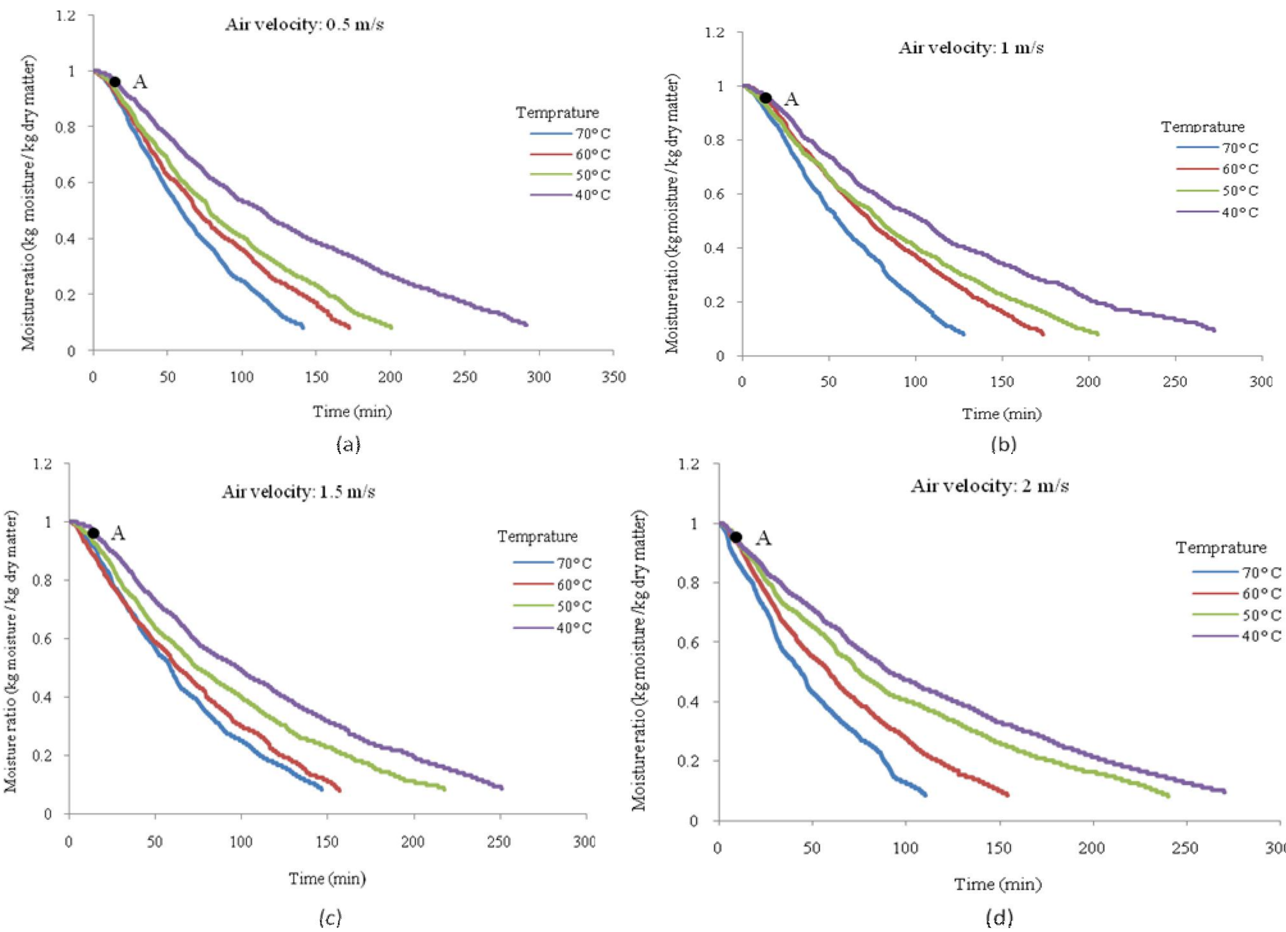

Figure 11. Product moisture ratio changes as a function of drying time in hot air flow drying process at different air velocities and temperatures.

Relations and theories of drying

In this paper, both functions of the drier (microwave and hot air flow) were evaluated separately. In the first experiment, only microwaves with powers of 500, 1000, 1500 and 2000 watt were applied. In the second experiment only hot air flow was used at different temperatures and velocities. In this study air temperature and velocity respectively were varied for 40, 50, 60 and 70 degrees of centigrade and 0.5, 1, 1.5 and 2 m/s.

Two parameters of moisture ratio and drying rate were studied for both experiments. Moisture ratio is an important factor in controlling drying process. Drying rate is also defined as the amount of moisture emerges from product per unit time and is an important factor in description of drying process. Dimensionless moisture ratio (MR) and drying rate (DR) in terms of (kgr moisture/kgrdry product ×second) are obtained by below equations (Kaya andAydın, 2009):

(2)

$$MR = \frac{M - M_e}{M_o - M_e}$$

(3)

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t}$$

Where M ،M_o ،M_e ،$M_{t+\Delta t}$ and M_t represents respectively instantaneous moisture, initial moisture, equilibrium moisture and moisture at the moments of t+Δt and t in terms of (kgr moisture/ kgr dry product) and t is drying time in terms of second.

Results and discussion

In order to describe and compare drying process in two methods of microwave and hot air flow and also to investigate effects of microwave power, air temperature and velocity on drying process of apple, moisture ratio and drying rate changes were represented as a function of time in different treatments.

Figure 11 shows that in all experiments moisture ratio gradually decreases at the beginning of the process (until point A). At this step, the product is being heated, then moisture ratio decreases with a sharper slope. This step is the decreasing step of drying which is continued until achieving the desired moisture content (end of drying process) but the slope gradually decreases. Most of the drying process occurs at the decreasing step of drying. This is in agreement with findings of Kaya et al. (2007) for apple, Doymaz (2007, 2006) for tomato and grapes. As it is seen in plots of figure 11, increasing air temperature has a significant effect on decreasing the drying time. For example, by increasing air temperature from 40°C to 70°C at a constant flow rate of 0.5 m/s, drying time decreases from 296 min to 141 min (Figure 11-a). Koyuncu et al. (2007) for cherry and Prabhanjan et al. (1995) for carrot reported similar results. However, at a constant air temperature drying time does not considerably decrease by increasing the air flow rate. For example, at constant temperature of 70°C, with increasing air flow rate from 0.5 m/s to 2 m/s drying time only decreases from 141 min to 111 min (figure 11-a). Similar results were obtained by Sacilikand Elicin (2006), Ramaswamy and Nieuwenhuijzen (2002) and Wang and Chao (2002) for apple.

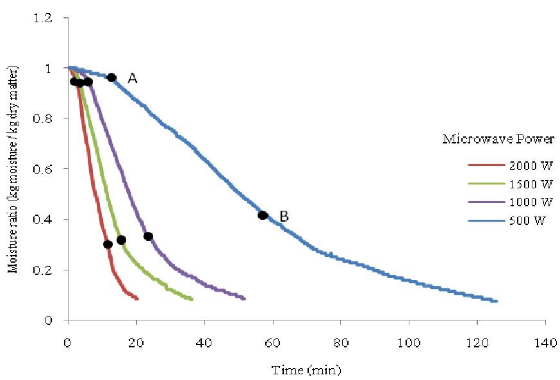

Figure 12.Changes of moisture ratio of product as a function of drying time in microwave drying process with different powers

Product moisture ratio Changes as a function of drying time in microwave drying can be divided into three steps (figure 12). Initially moisture ratio of product decreases slowly (until point A) while the product is being heated. Then, moisture ratio decreases progressively (until point B). This step, during which a part of drying process occurs, is the drying process with constant rate. Then decreasing step of drying process begins during which moisture ratio decreases with a decreasing slop until the end of process. This result is in agreement with results obtained by Al-Harahsheh et al. (2009) in drying process of tomato. Based on Figure 12, it is obvious that increasing microwave power has a significant effect on reduction of drying time. For example, when power is increased from 500 w to 2000 w, drying time reduces from 125 min to 20 min (figure 12). Consequently, process time until desired moisture content is decreased to one-sixth.

Drying rate of the product in different treatments of hot air flow is shown in figure 13 as a function of drying time. At the beginning of the drying process, rising drying rate is marked in all experiments. As noted during this step the product is being heated. Then the decreasing step begins and it is found that drying rate falls until the end of drying process. With increasing air temperature, drying rate decreases progressively and drying time decreases. This indicates the significant effect of air temperature on drying rate. However, increasing air flow rate has no considerable effect on drying rate of process (figure 13).

Considering Figure 13, it is observed that when the product is being heated, drying rate increases until it reaches a maximum point and then drying process continues with a constant rate slope during a small time interval. Next step is the decreasing step of drying process during which a reduction in drying rate continues till the desired moisture content is achieved. Effect of increasing microwave power on decreasing drying time and increasing drying rate is clearly observable such that increasing microwave power causes drying rate tohave higher slopesin all steps of drying. Thiscan be attributed an increase in internal temperature of the product due to rising microwave power and consequently increasing moisture gradient. In drying apple slices by hot air flow, the decreasing step of process beginsafter the product was heated whilein microwave drying process, a constant drying rate step,during which some part of drying process occurs,begins after this step. In microwave drying process, the decreasing step of drying process has a less contribution in total drying process because some moisture content of the product is dried during constant rate step. Drying by microwave takes less time than drying by hot air flow (compare figures 11 and 12). Also drying rate significantly increases in microwave method comparing to hot air flow method (compare figures 13 and 14).

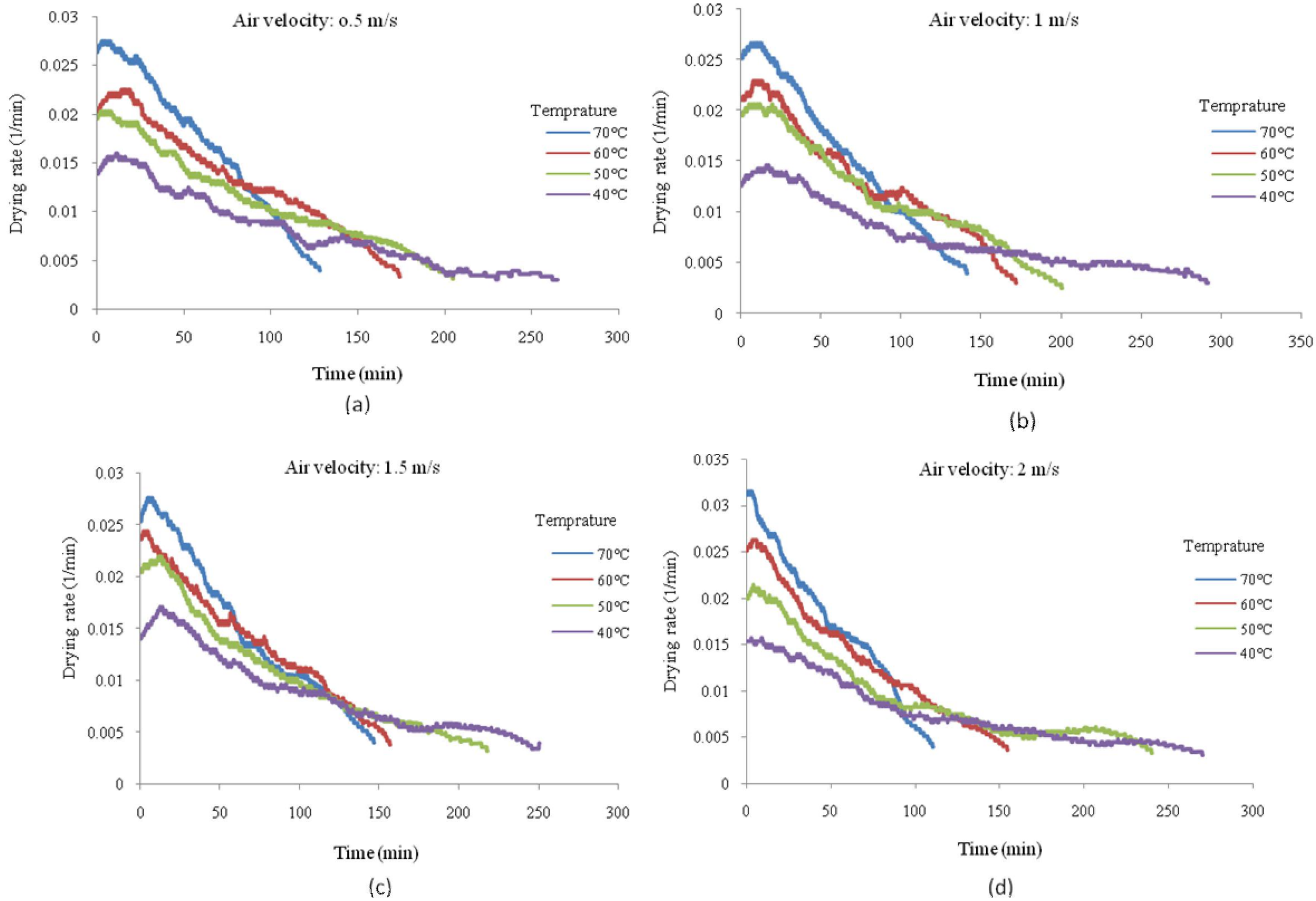

Figure 13. Drying rate versus time in hot air flow drying process at different temperatures and flow rates

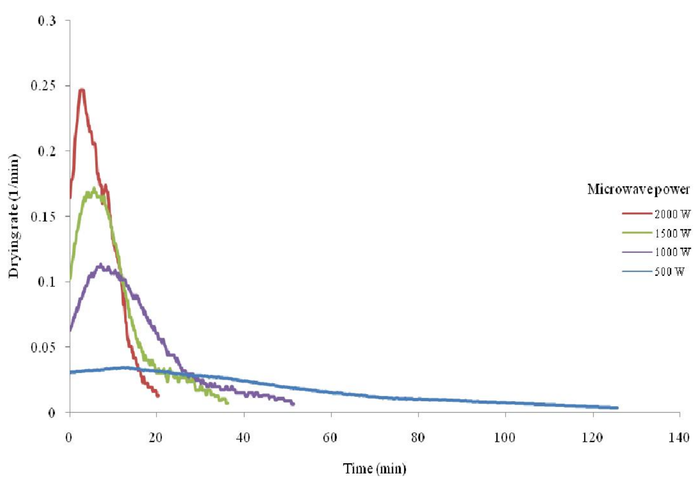

Figure 14.Changes of drying rate versus drying time in microwave drying method with different powers

Conclusion

In this paper, one microwave hot air flow drier was designed and manufactured. Evaluation results revealed that drying by microwave was more efficient than hot air flow drying in significantly reducing drying time and increasing drying rate. In hot air flow method, increasing air temperature had a significant effect on rising drying rate and reducing drying time. However, the effect of flow rate of inlet air on drying rate was negligible. It was observed that rising microwave power obviously caused a reduction in drying time and an increase in drying rate. This devise is capable of drying thin slices of different fruits and depending on optimum drying conditions for various fruits microwave can be used as pretreatment or post-treatment. Microwave-hot air flow combination drying is also possible using this drier.

References

1. Abbasi Souraki, B. and Mowla, D. 2008. Experimental and theoretical investigation of drying behavior of garlic in an inert medium fluidized bed assisted by microwave. Journal of Food Engineering. 88: 438–449.
2. Al-Harahsheh, M., Al-Muhtaseb, A. H. and Magee, T.R.A., 2009. Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Engineering and Processing. 48: 524–531.
3. Ampratwum, D. B. 1998. Design of solar dryer for dates. AMA. 29(3): 59-62.
4. Basunia, M. A. and Abe .T. (2001). Design and construction of a simple three-shelf solar rough rice dryer. AMA, 32 (3): 54-59.
5. Andres, A., Bilbao, C. and Fito, P., 2004. Drying kinetics of apple cylinders under combined hot air–microwave dehydration. Journal of Food Engineering. 63: 71–78.
6. AOAC, Official methods of analysis, Arlington, VA: Association of Official Analytical Chemists; 1990. Das, I., Das, S. K. and Bal, S., 2004. Specific energy and quality aspects of infrared (IR) dried parboiled rice. Journal of Food Engineering. 68: 249-255.
7. Das, I., Das, S. K. and Bal, S., 2004. Specific energy and quality aspects of infrared (IR) dried parboiled rice. Journal of Food Engineering. 68: 249-255.
8. Doymaz, I. 2006. Drying kinetics of black grapes treated with different solutions. Journal of Food Engineering. 76: 212–217.
9. Doymaz, I. 2007. Air-drying characteristics of tomatoes. Journal of Food Engineering 78: 1291–1297.
10. Doymaz, I. 2008. Convective drying kinetics of strawberry. Chemical Engineering and Processing. 47: 914–919.
11. Funebo, T. and Ohlsson, T. 1998. Microwave-assisted air dehydration of apple and mushoom. Journal of Food Engineering. 38(3): 353-367.
12. Gatea, A. A. 2011. Design and construction of a solar drying system, a cylindrical section and analysis of the performance of the thermal drying system. African Journal of Agricultural Research Vol. 6(2): 343-351.
13. Goksu, E. I., Sumnu, G. and Esin, A., 2005. Effect of microwave on fluidized bed drying ofmacaroni beads. Journal of Food Engineering. 66: 463–468.
14. Gunasekaran S. Pulsed microwave-vacuum drying of food materials. Drying Technology. 1999; 17(3): 395-412.
15. Hu, Q., Zhang, Min., Mujumdar, A. S., Xiao, G. and Sun, J. 2006. Drying of edamames by hot air and vacuum microwave combination. Journal of Food Engineering. 77: 977–982.
16. Kaya, A., Aydın, O. and Demirtas, C. 2007. Drying Kinetics of Red Delicious Apple. Biosystems Engineering. 96 (4): 517–524.
17. Kaya, A. and Aydın, O. 2009. An experimental study on drying kinetics of some herbal leaves. Energy Conversion and Management. 50: 118-24.
18. Kouchakzadeh, A. and Shafeei, S. 2010. Modeling of microwave-convective drying of pistachios. Energy Conversion and Management 51: 2012–2015.
19. Koyuncu, T., Tosun, I. and Yunus, P. 2007. Drying characteristics and heat energy requirement of cornelian cherry fruits (Cornus mas L.). Journal of Food Engineering 78: 735–739.
20. Li, Z., Raghavan, G. S. V., Wang, N. and Vigneault, C. 2011. Drying rate control in the middle stage of microwave drying. Journal of Food Engineering. 104: 234–238.
21. Prabhanjan, D. G., Ramaswamy, H. S. and Raghavan, G. S. V. 1995. Microwave assisted convective air drying of thin layer carrots. Journal of Food Engineering. 25: 283–293.
22. Ramaswamy, H. S. and van Nieuwenhuijzen, N. H. 2002. Evaluation and modeling of two-stage osmo-convective drying of apple slices. Drying Technology. 20(3): 651–667.
23. Sacilik, K. and Elicin, A. K. 2006. The thin layer drying characteristics of organic apple slices. Journal of Food Engineering. 73: 281–289.
24. Sharmaa, G.P., Prasadb, S. and Chahara, V.K., 2009. Moisture transport in garlic cloves undergoing microwave-convective drying, food and bioproducts processing. 87: 11–16.
25. Sumnu, G., Turabi, E. and Oztop, M. 2005. Drying of carrots in microwave and halogen lamp–microwave combination ovens. LWT. 38: 549–553.
26. Wang, J. and Chao, Y. 2002. Drying characteristics of irradiated apple slices. Journal of Food Engineering. 52(1): 83–88.

6/29/2012