IJABBR- 2014- eISSN: 2322-4827

International Journal of Advanced Biological and Biomedical Research

Journal homepage: www.ijabbr.com

Original Article

Evaluation of Energy Consumption of Potato Slices Drying Using Vacuum-Infrared Method

Negar Hafezi*[1], Mohammad Javad Sheikhdavoodi[2], Seyed Majid Sajadiye[2], Mohammad Esmail Khorasani Ferdavani[2]

[1]Msc. Student, Department of Mechanics of Agricultural Machinery and Mechanization, Faculty of Agriculture, Shahid Chamran University, Ahvaz, Iran
[2]Associate Professor, Department of Mechanics of Agricultural Machinery and Mechanization, Faculty of Agriculture, Shahid Chamran University, Ahvaz, Iran

ARTICLE INFO

Article history:
Received: 02 August, 2014
Revised: 26 August, 2014
Accepted:18 September, 2014
ePublished: 30 October, 2014

Key words:
Potato
Drying
Vacuum
Infrared radiation,
Energy consumption

ABSTRACT

Objective: The main objective pursued in this paper is to investigate the energy consumption for drying of potato slices using vacuum-infrared drying method. **Methods:** Drying of potato slices with the thicknesses of 1, 2 and 3 mm were conducted at vacuum levels of zero (without vacuum), 20, 80 and 140 mm [Hg], infrared radiation at power levels of 100, 150 and 200 W in the three repetition. **Results:** The results show that with the slice thickness decreases, acts of vacuum and increasing lamp power, energy consumption be reduced. Maximum of energy consumption occurred in a vacuum of 140 mm Hg, but in general it can be stated that by applying vacuum, energy consumption is reduced due to the shortening of the drying time. Data analysis showed that use of vacuum in conjunction with infrared radiation drying increased energy consumption in comparison to merely infrared drying. In the combined vacuum-infrared process, drying time and consequently energy consumption decreased in comparison to the merely infrared drying. The maximum thermal utilization efficiency (31.01%) and minimum energy requirements (5.3 kWh/kg H_2O) was calculated for drying of potato slices computed at infrared power of 150 W without vacuum at thickness of 1 mm. The minimum thermal utilization efficiency (2.13%) and maximum energy requirements (185.14 kWh/kg H_2O) for drying of potato slices was achieved at infrared radiation power of 100 W with vacuum level of 80 mm [Hg] at thickness of 2 mm.

1.INTRODUCTION

Fruits and vegetables are agricultural products which is known for their rich vitamins, high concentration of moisture and low fats. They are highly perishable due to excess moisture present in them especially at harvest time. Fruits and vegetables are seasonal crops and are mostly available during the production season. Potatoes are the fourth most important vegetable crop for human nutrition in the world. Food drying is the most important process for preserving agricultural products since it has a great effect on the quality of the dried products (Doymaz, 2004). Potato chips have been popular snacks for more than a century (Pedreschi et al., 2005) and its production is indeed a more competitive industry than other snack productions (Garayo and Moreira, 2002). Currently, there are demands for low-fat or fat-free snack products, which have been the driving force of the snack food industry (Moreira, 2001). Drying as one of the most common

---

***Corresponding Author:** Negar Hafezi, Msc. Student, Department of Mechanics of Agricultural Machinery and Mechanization, Faculty of Agriculture, Shahid Chamran University, Ahvaz, Iran(nhafezi05@yahoo.com)

preservation methods could therefore be a feasible alternative for production of low-fat or fat-free potato chips with desirable color and textural characteristics. Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. The moisture can be either transported to the surface of the product and then evaporated, or evaporated internally at a liquid vapor interface and then transported as vapor to the surface (Gogus, 1994). Drying is the most common form of food preservation. This process improves the food stability, since it reduces considerably the water and microbiological activity of the material and minimizes physical and chemical changes during its storage (Hatamipour, 2007). Drying of food products has been a very important sector of industry for many years. Drying is the most energy intensive process in food industry. Therefore, new drying techniques and dryers must be designed and studied to minimize the energy cost in drying process (Kocabiyik and Tezer, 2009). Microbial activities are not active when the moisture content of a product is below 10 %. Hence, harvested vegetables must be stored dry (5% moisture content on wet basis) to prevent attack and deterioration by activities of microorganisms and fungi (FAO, 1981). Considering the fact that the highest energy consumption in agriculture is associated with drying operations, different drying methods can be evaluated to determine and compare the energy requirements for drying a particular product.

Dried fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method which used, which depends on the type of food and the type of characteristics of the final product (Mujundar, 1987). Thermal drying operations are found in almost all industrial sectors and are known, according to various estimates, to consume 10-25% of the national industrial energy in the developed world (Kemp, 2012). In order to reduce the energy requirement during the dehydration process and also to minimize the quality degradation of the dried products, it is necessary to select an efficient drying system. Increasing concern for product quality and the need for minimized processing and energy costs have led to a more detailed study and understanding of drying of food materials. This has also revolutionized the design and development of drying systems (Umesh Hebbar et al., 2004). Infrared processing has been tried in baking, roasting, thermal treatments (blanching, pasteurization, sterilization, etc.) and drying of foodstuffs (Umesh Hebbar et al., 2004). Infrared radiation (IR) drying which has received much attention is one possible means for the above purpose. In the process of infrared radiation drying, the energy in the form of electromagnetic wave is absorbed directly by the product without loss to the environment leading to considerable energy savings, uniform temperature distributions in the product while drying, and a reduced necessity for air flow across and keeping good product quality (Ratti and Mujumdar, 1995; Sharma et al., 2005). Dryers are one of the most important equipment in food processing industries. Many dryers have been developed and used to dry agricultural products in order to improve their storage conditions. Most of the dryers use either expensive source of energy such as electricity or a combination of solar energy and other forms of energy (Ehiem et al., 2009).

In IR drying, special infrared lamps are used to extract moisture from the material being dried. In this method, the air surrounding wet matter flows using a suction device (vacuum pump) to remove humidity released by the matter from its vicinity in order for it to face less resistance while avoiding food stuff surface saturation with dump. Infrared radiation drying has the unique characteristics of energy transfer mechanism. During Infrared radiation, the energy in form of electromagnetic wave is absorbed directly by the product without loss to the environment, leading to considerable energy savings. Energy analyses have been conducted for different drying methods and conditions for products, such as carrots (Nazghelichi et al., 2010), mushroom slices (Motevali et al., 2011a), sour pomegranates (Motevali et al., 2011b), and red pepper (Kowalski and Mierzwa, 2011). In vacuum drying method due to lack of oxygen in dryer ambiance and unwanted reduction of reactions in food, the quality of dried food in this method is higher than the others (Motevali et al., 2011a; Motevali et al., 2011b). Also applying vacuum in food drying causes expansion of air and vapor and creates puff state in the matter. Due to the high energy consumption in this method, vacuum drying can be used for highly sensitive and high value-added products (Motevali et al., 2011a; Motevali et al., 2011b). For drying under vacuum (or vacuum drying), moisture within the product being dried evaporates at lower temperatures (lower than 100°C) giving better product quality, especially in the cases of foods or agricultural products, which are heat-sensitive in nature. When the advantages of the two dying methods are combined, energy efficiency of the drying process is enhanced and degradation of dried product quality is also reduced. Nimmol et al. (2010) proposed a combined far-infrared radiation and vacuum drying system for heat-sensitive materials; carrot cube was used as a test material. In their system operation of a far-infrared radiator was controlled by the surface temperature of the sample (at about 1 mm below the top surface of the sample). Drying experiments were conducted at the controlled surface temperatures of 60, 70 and 80°C and absolute chamber pressures of 7 and 10 kPa. Mongpraneet et al. (2002) examined the drying behavior of the leaf parts of welsh onion undergoing combined far infrared and vacuum drying. The results showed that the radiation intensity levels dramatically influenced the drying rate and the dried product qualities. Mongpraneet et al. (2004) also determined the energy consumption in far infrared drying of onion. From their experiments, less than half of the energy input was utilized for evaporating water from the onion. Approximately 73-99% of the energy input, depending on the dryer configuration, was converted into radiant energy. Swasdisevi et al. (2009) developed a mathematical model for predicting the moisture content and temperature of banana slices undergoing vacuum-far radiation. The results revealed that the vacuum pressure, temperature and thickness had significant effects on the drying kinetics. Bakal et al. (2011) investigated the effect of air temperature and two different shapes (cubical and cylindrical) with 3 aspect ratio of each shape on the drying kinetics of potato in a fluidized bed dryer. They reported that the Page model best described the drying behavior of potatoes. The present work is aimed at studying the effects of drying kinetics on energy consumption, specific energy consumption and thermal utilization efficiency of potato slices by infrared radiation under vacuum.

2. MATERIALS AND METHODS

2.1. Experimental set-up

A laboratory scale vacuum-infrared dryer, developed at the Agricultural Machinery and Mechanization Engineering Laboratory of Shahid Chamran University (Iran). A schematic diagram of the apparatus for combined vacuum and infrared radiation drying system is shown in Fig. 1. The dryer consists of a stainless steel drying chamber, which is designed to withstand lower level of pressure; a laboratory type piston vacuum pump, which is used to maintain vacuum in the drying chamber; an infrared lamp with power of 250 W (OSRAM, Slovakia), which is used to supply thermal radiation to a drying product; and a control system for the infrared radiator.

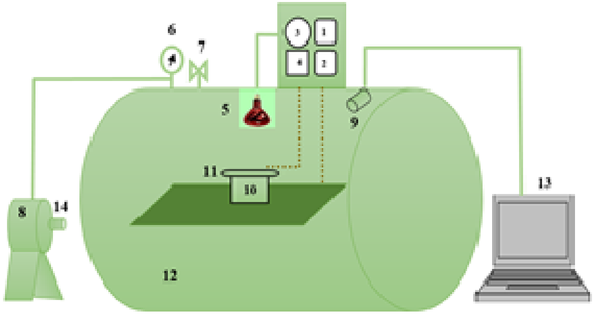

Fig.1. A schematic diagram of a vacuum-infrared drying system: 1) humidity sensor; 2) thermocouples; 3) infrared lamp power controller; 4) voltmeter; 5) infrared lamp; 6) vacuum gauge; 7) vacuum break-up valve; 8) vacuum pump; 9) video camera; 10) electronic weight scale; 11) sample tray; 12) drying chamber; 13) laptop; 14) air outlet duct.

2.2. Materials and Methods

Fresh potatoes were purchased from a local market in Hamadan province (Iran). The samples were stored in refrigerator to prevent undesirable effect at about 5-6°C and relative humidity of about 85%. Potatoes were peeled, washed, and sliced with thickness of 1, 2 and 3 mm by a manual slicer. The samples were blanch in solution containing 2% NaCl for 3 min. The initial moisture content of the fresh samples was 77% (w.b), which was determined in triplicate by using a convection oven at 70°C for 24 h (AOAC, 1990). Potato slices were dried in a vacuum chamber with vacuum levels of zero (without vacuum), 20, 80 and 140 mm [Hg] and infrared radiation powers of 100, 150 and 200 Watts in the three repetition. The distance between the infrared lamp and the sample tray was set at 15 cm. The change samples mass during the drying was detected continuously using an electronic weight scale (Lutron, GM-1500P, Taiwan) with an accuracy of ±0.05 g. The temperatures of the drying chamber and of the drying sample were measured continuously using thermocouples (SAMWON ENG, SU-105KRR). In start of experiments relative humidity and temperatures of the drying chamber were measured (35% and 50°C respectively). The drying experiments were performed until the sample moisture content of 6-7% (w.b) was obtained.

2.3. Theoretical principle

The moisture content of the samples was found during the drying process at different length of the dryer using equation (1).

$$M_w = \left(\frac{W_w - W_d}{W_w} \right) \times 100 \qquad (1)$$

Where: M_w is the moisture content wet basis (%); W_w is the initial weight of potato samples (gr); W_d is the dry weight of potato samples (gr). To find a suitable mathematical model, the moisture content data at different thickness, vacuum levels and infrared power were converted to the moisture ratio (MR, dimension less) expression by using following equation.

$$MR = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

Where: MR is the moisture content ratio; Mt is the moisture content at any drying time on wet basis (kg water/kg wet material); Me is the equilibrium moisture content on wet basis (kg water/kg wet material); Mo is the initial moisture content on wet basis (kg water/kg wet material).

2.3.1. Evaluation of energy consumption

In this study, energy consumption of dying process came from the electrical energy consumed by the operation of the vacuum pump and the infrared lamp. Energy consumption by vacuum pump can be calculated using Eq. (3).

$$E_1 = V \times I \times T \tag{3}$$

Where E_1 is the power consumed by the pump (kW h), V the nominal pump voltage (kW), I is the electric current intensity in the pump and t is drying time (h).

Rate of energy expenditure by the infrared lamp is constant at any given time and is obtained using Eq. (4). The infrared lamp in this dryer is 250 W at 230 V coated electric.

$$E_2 = V \times I \times T \tag{4}$$

Where E_2 represents the energy consumed by the IR lamp; V is lamp voltage (v), I is the electric current intensity in the lamp and t is drying time (h).

$$E_t = E_1 + E_2 \tag{5}$$

Where E_t is total needed energy for drying at each condition of the experiments (kWh).

2.3.2. Evaluation of specific energy consumption

Specific energy consumption was defined as the energy required for removing a unit mass of water in drying the potato slice that is calculated using Eq. (6).

$$E_s = \frac{E_t}{m_w} \tag{6}$$

Where E_s is specific energy requirement (kWh/kg) and W_0 is the amount of water taken out of the product (kg).

2.3.3. Evaluation of Thermal utilization efficiency

Thermal utilization efficiency is defined as the ratio of latent moisture evaporation heat of sample to the amount of energy required to evaporate moisture from free water (Umesh Hebbar et al., 2004). Considering that the highest energy consumption in agriculture is related to drying the product, different drying methods can be evaluated to calculate and compare the energy requirements for drying a particular with each product. The vacuum-infrared drying efficiency was calculated as the ratio of the heat energy utilized for evaporating water from the sample to the heat supplied by the vacuum-infrared (Soysal, 2004; Yongsawatdigul and Gunasekaran, 1996).

$$\eta = \frac{m_w \times \lambda_w}{3600 \times E_t} \times 100 \tag{7}$$

Where η is the vacuum-infrared drying efficiency (%); m_w is the mass of evaporated water (kg); and λ_w is the latent heat of vaporization of water (kJ/kg). The latent heat of vaporization of water at the evaporating temperature of 100°C was taken as 2257, kJ/kg (Hayes, 1987).

3. RESULTS AND DISCUSSION

3.1.The correlation coefficient of energy consumption and specific energy requirement

The Pearson correlation coefficient is a measure of the linear correlation (dependence) between two variables X and Y, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and −1 is total negative correlation. It is widely used in the sciences as a measure of the degree of linear dependence between two variables. According to Table 1, The Pearson correlation test (R=0.323) between thickness and the amount of energy consumption is significant at 5% level of confidence. The value of the Pearson correlation test (R=0.560) between vacuum and the amount of energy consumption is significant at 1% level of confidence. However, that infrared radiation power don't had any significant effects on the amount of energy consumption. This coefficients suggests that direct proportion have between vacuum and thickness of slice with the energy consumption. Also according to Table 1 was indicated that factors of vacuum (R=0.323) and infrared radiation power (R=-0.347) have significant effect at 5% level of confidence on the specific energy requirement. In other words, the specific energy consumption is directly related to the amount of vacuum and has to be inversely related to radiation power. However, that thickness of slice don't had any significant effects on the specific energy requirement.

Table 1:

Pearson correlations between independent and dependent variables

		Thickness	Vacuum	Power
Energy Consumption	Pearson Correlation	0.323^{*}	0.560^{**}	-0.187
	Sig. (1-tailed)	0.027	0.000	0.137
Specific Energy Requirement	Pearson Correlation	0.054	0.323^{*}	-0.347^{*}
	Sig. (1-tailed)	0.377	0.027	0.019

*. Correlation is significant at the 0.05 level (1-tailed).
**. Correlation is significant at the 0.01 level (1-tailed).

3.2. The regression equation of energy consumption

Correlation of independent and dependent variables in a multivariate linear regression shown in Table 2 were analyzed using SPSS software. Thickness of slice, vacuum and infrared radiation power variables are explaining 67.3% of the variation in energy consumption.

Considering the significance of the final multivariable regression model, energy consumption can be estimated using the following equation.

$$Y = 0.469 + 0.165*T + 0.004*V$$

Where, T is the thickness of slice and V is the vacuum.

Table 2:

Results of multivariate regression analysis

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	**(Constant)**	0.469	0.255		1.839	0.075
	Thickness	0.165	0.067	0.323	2.467	0.019
	Vacuum	0.004	0.001	0.560	4.280	0.000
	Power	-0.002	0.001	-0.187	-1.433	0.162

a. Dependent Variable: Energy Consumption

Fig. 2 shows the amount of energy needed by the vacuum-infrared to dry of potato slices. The use of vacuum in conjunction with infrared radiation drying increased energy consumption in comparison to merely infrared drying. However, drying time and consequently energy consumption in comparison to the merely infrared drying. Maximum and minimum energy consumption values were calculated to be 1.47 kWh and 0.1 kWh for infrared power 100 W with vacuum level 80 mm [Hg] in thickness of 3 mm and IR power of 150 W without vacuum in thicknesses of 1 mm.

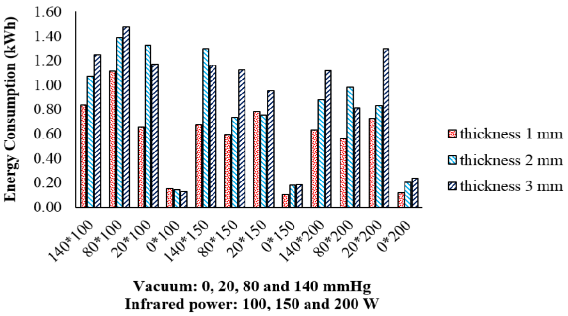

Fig. 2. Energy consumption in vacuum-infrared drying of potato slices

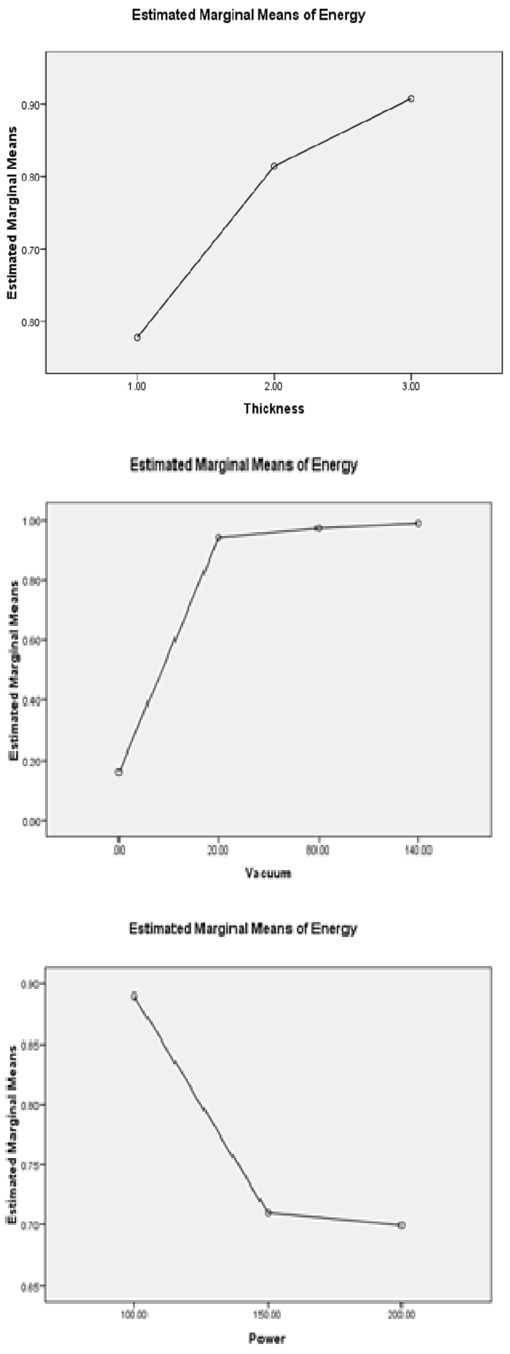

Fig. 3. Effect power, vacuum and thickness on the energy consumption for vacuum-infrared drying of potato slices

Fig. 3 shows the effect of lamp power, vacuum and slice thickness of potatoes on the energy consumption during the drying process. The results show that with the slice thickness decreases, acts of vacuum and increasing lamp power, energy consumption be reduced. Maximum of energy consumption occurred in a vacuum of 140 mm Hg, but in general it can be stated that by applying vacuum, energy consumption is reduced due to the shortening of the drying time.

Fig. 4 shows values of specific energy (energy required for drying 1 kg of potato slices). The minimum and the maximum energy requirements for drying of potato slices were also determined as 5.3 kWh/kg H_2O and 185.14 kWh/kg H_2O for IR power 150 W without vacuum in thickness of 1 mm and IR power 100 W with vacuum level 80 mm [Hg] in thickness of 2 mm, respectively.

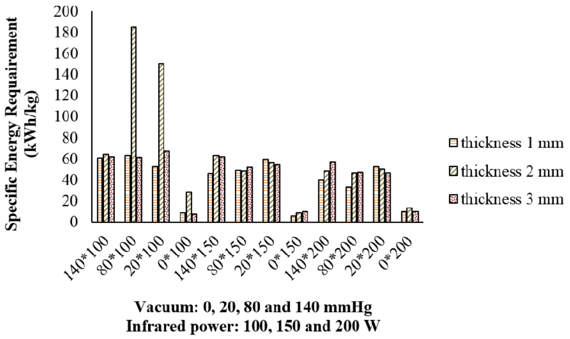

Fig. 4. Specific energy requirement in vacuum-infrared drying of potato slices

Fig. 5 shows the average thermal utilization efficiency in this drying method was estimated 7.43% and the maximum thermal utilization efficiency (31.01%) for drying of potato slices was computed at infrared power 150 W without vacuum in thickness of 1 mm. The minimum thermal utilization efficiency (2.13%) was computed at IR power 100 W with vacuum level 80 mm [Hg] in thickness of 2 mm.

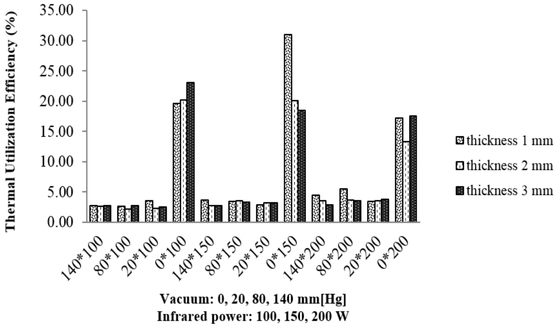

Fig. 5. Thermal Utilization Efficiency in vacuum-infrared drying of potato slices

CONCLUSION

The drying kinetics of the potato slices was investigated in a vacuum-infrared dryer. The moisture content and drying rates were influenced by the infrared power, vacuum and thickness. Results showed that the drying time decreased with the increase of the infrared radiation power and the decrease of air pressure (acts of vacuum). Minimum energy consumption was observed in drying potato slices with infrared treatment (150 W without vacuum) while the maximum energy consumption occurred in the vacuum-infrared treatment (100 W with vacuum level 80 mm [Hg]).

REFERENCES

AOAC. (1990). Official Methods of Analysis. No. 934-06. Association of Official Chemists, Washington, DC.

Bakal, S.B., Sharma, P.G., Sonawan, S.P. and Verma, R.C. (2011). Kinetics of potato drying using fluidized bed dryer. Journal of Food Science and technology. 19: 127-135.

Doymaz, I. (2004). Convective air drying characteristics of thin layer carrots. Journal of Food Engineering, 61: 359-364.

Ehiem, J.C., Irtwange, S.V. and Obetta, S.E. (2009). Design and Development of an Industrial Fruit and Vegetable Dryer. Research Journal of Applied Sciences, Engineering and Technology, 1(2): 44-53.

FAO. (1981). Food loss prevention in perishable crop. Food and Agriculture Organization of the United Nations.

Garayo, J. and Moreira, R. (2002). Vacuum frying of potato chips. Journal of Food Engineering, 55: 181-191.

Gogus, F. (1994). The effect of movement of solutes on milliard reaction during drying. Ph.D. Thesis, Leeds University, Leeds, UK.

Hatamipour, M.S., Kazemi, H.H., Nooralivand, A. and Nozarpoor, A. (2007). Drying characteristic s of six varieties of sweet potatoes in different dryers. Food Bioprod Process, 85(C3): 171-177.

Hayes, G.D. (1987). Food Engineering Data Handbook. England: Longman Scientific and Technical.

Kemp, I.C. (2012). Fundamentals of Energy Analysis of Dryers. Modern Drying Technology. Volume 4: Energy Savings, First Edition, pp 1-46.

Kocabiyik, H. and Tezer, D. (2009). Drying of carrot slices using infrared radiation. Int J Food Sci Technol, 44: 953–959.

Kowalski, S. J., and Mierzwa, D. (2011). Hybrid drying of red bell pepper: energy and quality issues. Drying Technology, 29: 1195 –1203.

Mongpraneet, S., Abe, T. and Tsurusaki, T. (2002). Accelerated drying of welsh onion by far infrared radiation under vacuum conditions. Journal of Food Engineering, 55: 147-156.

Mongpraneet, S., Abe, T. and Tsurusaki, T. (2004). Far infrared- vacuum and convection drying of welsh onion. Transactions of the ASAE, 45: 1529-2535.

Moreira, R. G. (2001). Impingement drying of food using hot air and superheated steam. Journal of Food Engineering, 49: 291–295.

Motevali, A., Minaei, S., Khoshtaghaza, M.H., and Amirnejat, H. (2011a). Comparison of energy consumption and Specific Energy Requirements of Different methods for drying mushroom slices. Energy, 36: 6433-6441.

Motevali, A., Minaei, S. and Khoshtagaza, M.H. (2011b). Evaluation of energy consumption in different drying methods. Energy Conversion and Management, 52(2): 1192–1199.

Mujundar, A. S. (1987). Handbook of Industrial Drying, Marcel Dekker Inc., New York, NY.

Nazghelichi, T., Kianmehr, M. H., and Aghbashlo, M. (2010). Thermodynamic analysis of fluidized bed drying of carrot cubes. Energy, 35(12): 4679–4684.

Nimmol, C. (2010). Vacuum Far-infrared Drying of Foods and Agricultural Materials. The Journal of KMUTNB. Japan, 20(1): 37-44.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. Food Research International, 38: 1–9.

Ratti, C. and Mujumdar, A.S. (1995). Infrared drying, in: A.S. Mujumdar, (eds.), Handbook of industrial drying: Volume 1, Marcel Dekker, NewYork.

Sharma, G.P., Verma, R.C., Pathare, P.B., (2005). Thin-layer infrared radiation drying of onion slices. Journal of Food Engineering, 67:361-366.

Soysal, A. (2004). Microwave Drying Characteristics of Parsley. Biosystems Engineering, 89(2): 167–173.

Swasdisevi, T., Devahastin, S., Sa-Adchom, P. and Soponronnarit. S. (2009). Mathematical modeling of combined far-infrared and vacuum drying banana slice. Journal of Food Engineering, 92: 100-106.

Umesh Hebbar, H., Vishwanathan, K.H., and Ramesh, M.N. 2004. Development of combined infrared and hot air dryer for vegetables. J. Food Eng, 65(4): 557–563.

Yongsawatdigul, J. and Gunasekaran, S. (1996). Microwave-vacuum drying of cranberries. Part II: Quality evaluation. Journal of Food Process Engineering, 20(12): 145–156.