VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

2.45 GHZ MICROWAVE DRYING OF COCOA BEAN

Muhammad Zamrun Firihu[1] and I. Nyoman Sudiana[2]
[1]Theoretical and Computational Physics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kampus Hijau Bumi Tridharma Anduonohu, Kendari, Indonesia
[2]Material Physics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kampus Hijau Bumi Tridharma Anduonohu, Kendari, Indonesia
E-Mail: muhammad.zamrun@uho.ac.id

ABSTRACT

Researches on drying by using microwaves energy, along with traditional methods of heating, are widely reported. In this paper, we analyze the experimental results of microwave drying of cocoa bean. Drying experiments were by using a domestic microwave oven which operated at three power levels. Microwave drying is based on a unique volumetric heating mode with electromagnetic radiation at 2,450 MHz. The responses of the agriculture product to dielectric heating result in rapid energy coupling into the moisture and lead to fast drying. A significant reduction in drying time in microwave drying is often accompanied by an improvement in product quality, making it a promising food dehydration technology. Preliminary theoretical analysis by using an analytical approach by using Dincer and Dost model for the drying of cocoa bean is presented. The study gives a brief description of efforts made to obtain basic drying parameters under different microwave drying conditions from experimental results.

Keywords: drying, microwave, cocoa bean, dincer and dost model.

1. INTRODUCTION

Agricultural products are dried to inhibit microbial development and quality decay. However, the extent of drying depends on product end-use. Products are dried after harvest to the moisture content that allows microbial stability during storage [1-2]. For examples, vegetables are blanched before drying to avoid rapid darkening, and drying is not only carried out to inhibit microbial growth, but also to avoid browning during storage. For fruits, the reduction of moisture acts in combination with its acid and sugar contents to provide protection against microbial growth. Other products as crackers are dried beyond the microbial growth threshold to confer a crispy texture, which is liked by consumers. Most farmers use conventional drying method (electric furnace or sun-drying method). Other possibilities are by using gas stream, vacuum drying, or microwave method.

Cocoa (Theobroma cacao L.) is a perennial cash crop and its natural habitat is the humid tropics. In most tropical countries, agricultural products like cocoa are harvested all the year round and the beans must be dried immediately after fermentation to reduce mass losses and prevent spoilage. The end products from cocoa bean especially chocolate and beverages are considered among the basic food in many countries of the world; however the quality of these end products is a function of how they are processed. The fermentation and drying of this crop are the major critical steps in the sequence of its processing. Drying can be achieved naturally by making use of solar energy or artificially by using heated cocoa bean dryers. However farmers are weary of the problem of excessive drying and quick drying of cocoa beans by heated dryers; because cocoa is sold by weight, excessive drying will not be economical in terms of amount of money received by farmers.

Generally, the moisture content of the cocoa bean is approximately 55% at the end of fermentation and this must be reduced to less than 8% before the cocoa can be stored sold or transported [3]. However if the moisture is reduced too much, the shells become too brittle and break but if moisture is too high, mould growth occurs during storage. The rate of drying is critical to final quality. Too slow or too rapid a drying rates result in excessively acid bean with case shrivelling. Most farmers use conventional drying method. Drying by using heat energy, the heating elements supply heat to the materials and energy absorbed only at surface and be transferred into the other part of materials by conduction which taking amount of time.

The use of microwave energy has been reported widely for sintering ceramics [4-10] as well as for drying food [11-12]. In a microwave furnace, the material will absorb microwave energy convert the energy into heat. Heat is generated internally within the materials resulting homogenous heating. In general, the time-averaged power dissipated per unit volume in a material can be expressed as [13].

$$P_v = \frac{1}{2\omega\varepsilon_0\varepsilon``|E|^2} \quad (1)$$

Where ε`` is the imaginary part of the complex dielectric constant of the material, ω is the angular frequency of the electric field E, and εo is the permittivity of free space.

An experiment of drying characteristics of cocoa bean by using a microwave furnace was successfully performed and reported previously. In this paper, analysis of experiment results of drying characteristics of cocoa bean by using a microwave furnace will be presented.

2. EXPERIMENTAL SETUP

2.1 Sample preparation

Cocoa beans with initial moisture content of 54% in average were obtained from a local farmer (Ladongi,

South East Sulawesi). Prior to drying, samples were selected then washed. All samples then were pellet and cut into slab shape with desired size of 10 mm in diameter and 3 mm in thickness.

2.2 Drying experiment

The microwave drying experiments were performed in a 2.45 GHz microwave oven (Panasonic NE-C236, Japan) [12]. The maximum automatic output microwave power is 800 W. The power consumption is 1.43 kW. Cocoa bean drying experiments were performed by using three power levels: high power was calculated as 600 W, medium power as 300 W and low power as 150 W. Two hundred grams of samples were placed in the oven. The microwave oven equipped by a temperature controlling system. Microwave powers were varied with samples.

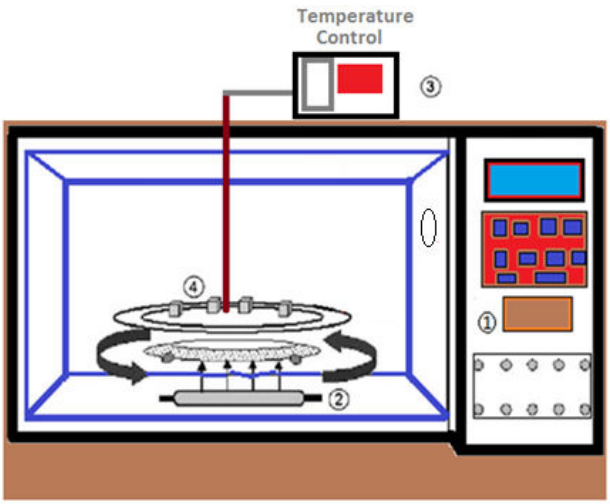

Figure-1. Schematic picture of a microwave drying system: (1) control; (2) lamp; (3) temperature control; (4) samples on turntable plat.

2.3 Analysis of drying experiment

The moisture content value was determined as:

$$M = (W_t - W_d)/W_d \quad (2)$$

where M is moisture content, Wt is the weight of sample (g) at any time and Wd is the weight of the dried sample. The analysis of microwave drying models can be classified into three categories, i.e. heat-mass transfer model, empirical model and diffusion model [14-15]. In this paper we use diffusion model models.

3 RESULTS AND DISCUSSIONS

3.1 Drying experiment

Drying curves of cocoa beans dried with different methods are presented in Figure-2. It shows that the moisture content and drying rate decreased continuously with drying. There are no constant rates drying because most crops as well as cocoa exhibit the constant rate drying characteristics at their critical moisture content. Cocoa exhibits a constant rate behaviour during drying, from moisture content of 70-100% [3]. However the initial moisture content in this experiment is not up to this range. At the falling rate period the movement of moisture within the cocoa to the surface is governed by diffusion since the material is no longer saturated with water. The graph shows that the moisture ratio decreased as the drying time increased. Figure-2 also exhibits a faster drying in the microwave compared than in the conventional furnace on all microwave powers. Microwave heating is mainly due to polarization and ionic conduction of water molecules in cocoa. Simplify can be described that the ionic conduction losses and due to dipolar rotation towards microwave frequencies with temperature. The absorption of microwave energy and conversion to heat is due to polarization and conduction would result in a rise in temperature, and this is given by the following equation [2]:

$$\frac{\Delta T}{\Delta t} = \frac{2\pi f \varepsilon_0 \varepsilon''_{eff} E^2_{rms}}{\rho c_p} \quad (3)$$

where, ε''_0 is the permittivity of free space (8.85x10-12 V/m3), ε''_{eff} is the relative effective dielectric loss due to ionic conduction and dipolar reorientation, f is the frequency (Hz), Erms is the root mean square of the electric field within the material (V/m), ρ is the bulk density of dielectric material (kg/m^3) and Cp is the heat capacity of the material at constant pressure (J/kg^{o}C). The water dipole attempts to continuously reorient in microwave's oscillating field. The dipole lags between the dipole and the field leads to an energy loss by heating. The ease of the movement depends on the strength and extent of the hydrogen bonded network.

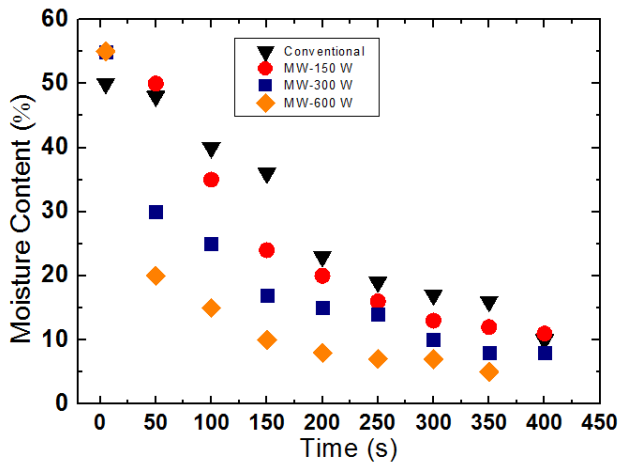

Figure-2. Drying curves of cocoa bean slabs (diameter of 10 mm) in a microwave with different microwave power and in an electric furnace (diameter of 10 mm).

3.2 Model of drying experiment

According to Fick's second law for diffusion. The governing Fickian equation is in the form of Fourier equation of heat transfer in which temperature (T) and

thermal diffusivity are replaced with moisture content (M) and moisture diffusivity, respectively. The time dependency of heat and moisture transfer equations can be written as following equation [16-18]:

$$\left(\frac{1}{y^m}\right)\left(\frac{\partial}{\partial y}\right)\left[y^m\left(\frac{\partial T}{\partial y}\right)\right] = \left(\frac{1}{\alpha}\right)\left(\frac{\delta T}{\delta t}\right) \quad (4)$$

and

$$\left(\frac{1}{y^m}\right)\left(\frac{\partial}{\partial y}\right)\left[y^m\left(\frac{\partial M}{\partial y}\right)\right] = \left(\frac{1}{D}\right)\left(\frac{\delta M}{\delta t}\right) \quad (5)$$

Where m= depend on shape, 0, for infinite slab, 1 for infinite cylinder, and 2 for sphere; y= radius for sphere and cylinder; α=thermal diffusivity; D= moisture diffusivity, and t= time.

By using dimensionless temperature and moisture content parameter, we can develop an unsteady state diffusion of moisture content in agriculture product from Fick's second law:

$$\left(\frac{\partial \phi}{\partial t}\right) = \left[\frac{\partial}{\partial z}\left(\frac{1}{D}\frac{\partial \phi}{\partial z}\right)\right] \quad (6)$$

$$\mathrm{D}\left(\frac{\partial^2 \phi}{\partial z^2}\right) = \left[\frac{\partial \phi}{\partial t}\right] \quad (7)$$

From Figure-2 we can assume that drying has an exponentially trend and should be following equation,

$$\phi = C \exp(-kt) \quad (8)$$

Where C = lag factor and k= drying coefficient

For one-dimensional transient moisture diffusion in an infinite slab, we can use Dincer and Dost Model [17-19]:

$$D = \frac{kY^2}{\mu^2} \quad (9)$$

where Y= half thickness of slab, and μ=coefficient of characteristic of drying equation

$$\mu = tg^{-1}(0.7564623\, B_i + 0.4255453 \quad (10)$$

Lag factor and drying coefficient are determined by drying experimental graphs then Biot number then can be calculated. By using those parameters, μ and D were then determined.

Preliminary calculation of the parameters is shown in Table-1. Detail model calculation results with various sample sizes will be published in another paper.

Table-1.

Microwave power (Watt)	**Cocoa bean samples**		**G**	**K(1/s)**	**μ**	**Bi**	**D (m^2/s)**
	Thickness (mm)	**Diameter** (mm)					
150	3	10	1.3823	0.03166	0.563	0.327	0.96
300	3	10	1.4782	0.05626	0.549	0.564	1.30
600	3	10	1.4973	0.08212	0.5791	0.756	2.77

4. CONCLUSIONS

Experiments of application microwave energy for drying cocoa beans have been performed. Slab cocoa bean samples with diameter of 10 mm and thickness of 3 mm were prepared. A domestic microwave oven operated at three power levels with temperature control was applied for drying experiment system. Conventional drying was used as a comparison by applied electric furnace. The microwave showed a faster drying than conventional ones at all microwave powers. Analysis of the experimental data was performed by using available theoretical models. Drying parameters determined by using the model and experimental drying graphs. This model could be used as a tool for microwave drying of cacao bean more efficiency.

ACKNOWLEDGEMENTS

Thanks to all members of Material Physics Laboratory and Theoretical and Computational Physics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Halu Oleo University for all facility supports.

REFERENCES

[1] M. O. Faborode, J. F. Favier, and O. A. Ajayi. 1995. On the Effects of Forced Air Drying On Cocoa Quality. Journal of Food Engineering. 25(4): 455-472.

[2] ASAE Standard S 358.2. 1983. Moisture Measurement of Grain and Seeds. 37th ed. American Society of Agricultural Engineers (ASAE), St. Joseph, Michigan, USA.

[3] M. C. Ndukwu. 2009. Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean. Agricultural Engineering International: CIGR Ejournal, 1091. Vol. XI.

[4] H. Aripin, S. Mitsudo, E. S. Prima, I. N. Sudiana, H. Kikuchi, Y. Fujii, T. Saito, T. Idehara, S. Sano, and S. Sabchevski. 2015. Crystalline mullite formation from

mixtures silica xerogel converted from sago-of alumina and a novel material waste ash, Ceramics International. 41(5): 6488-6497.

[5] H. Aripin, S. Mitsudo, I. N. Sudiana, T. Saito, and S. Sabchevski. 2015. Structure Formation of a Double Sintered Nanocrystalline Silica Xerogel Converted From Sago Waste Ash. Transactions of the Indian Ceramic Society. Transactions of the Indian Ceramic Society. 74(1): 11-15

[6] M. Z. Firihu and I. N. Sudiana. Microwaves Enhanced Sintering Mechanisms in Alumina Ceramic Sintering Experiments. Contemporary Engineering Sciences. 9(5): 237-247.

[7] I. N. Sudiana, S. Mitsudo, T. Nishiwaki, P. E. Susilowati, L. Lestari, M. Z. Firihu, and H. Aripin. 2015. Effect of Microwave Radiation on the Properties of Sintered Oxide Ceramics. Contemporary Engineering Sciences. 8(34): 1607-1615.

[8] I. N. Sudiana, R. Ito, S. Inagaki, K. Kuwayama, K. Sako, and S. Mitsudo. 2013. Densification of Alumina Ceramics Sintered by Using Sub-millimeter Wave Gyrotron, Int. J. of Infrared, Millimeter, and Terahertz Waves. 34(10): 627-638.

[9] S. Mitsudo, S. Inagaki, I. N. Sudiana, and K. Kuwayama. 2013. Grain Growth in Millimeter Wave Sintered Alumina Ceramics. Advanced Materials Research. 789: 279-282.

[10] H. Aripin, S. Mitsudo, E. S. Prima, I. N. Sudiana, H. Kikuchi, S. Sano, and S. Sabchevski. 2013. Microstructural and Thermal Properties of Nanocrystalline Silica Xerogel Powders converted from Sago Waste Ash Material. Materials Science Forum. 737: 110-118.

[11] Q. G. Hu, M. Zhang, A. S. Mujumdar, G. N. Xiao, and S. Jin-cai. 2006. Drying of Edamames by Hot Air and Vacuum Microwave Combination. J. of Food Engineering. 77:977-982.

[12] I. N. Sudiana, S. Mitsudo, L. O. Ngkoimani, L. Aba, H. Aripin, and I. Usman. 2014. Fast Drying of Cocoa Bean by Using Microwave. The Celebes International Conference on Earth Science (CICES2014), Kendari, Indonesia.

[13] W. H. Sutton. 2005. Microwave Processing of Ceramic Materials, Microwave Solutions for Ceramic Engineers, Am. Cer. Soc., Ed. by D. E. Clark, D. C. Folz, C. E. Folgar, M. M. Mahmoud. pp. 35-65.

[14] V. T. Karathanos and V. G. Belessiotis. 1999. Application of a thin layer equation to drying data fresh and semi- dried fruits. Journal of Agricultural Engineering Research. 74(4): 355-361.

[15] W. A. M. McMinn, M. A. M. Khraisheh, and T. R. A. Magee. 2003. Modeling the mass transfer during convective, microwave and combined microwave-convective drying of solid slabs and cylinders. Food Research International. 36(9-10): 977-983.

[16] A. K. Hakhi and A. Amanifard. 2003. Heat and Mass Transfer during drying of food Products. Brazilian Journal of Chemical Engineering. 25(3): 491-501.

[17] I. Dincer. 1998. Moisture transfer analysis during drying of slab woods. International Journal of Heat and Mass Transfer. 34(4): 317-320.

[18] I. Dincer and S. Dost. 1995. An analytical model for moisture diffusion in solid objects during drying, Drying Technol. 13(1-2): 425-435.

[19] I. Dincer and S. Dost. 1996. A modeling study for moisture diffusivities and moisture transfer coefficients in drying of solid objects, Int. J. Energy Res. 20(6): 531-539.