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Determination of Dielectric Properties of Tomato Juice Relevant to Microwave Sterilization Process

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ABSTRACT

Dielectric properties of tomato juice including dielectric constant, loss factor and penetration depth relevant to microwave sterilization process were measured over 25°C to 121°C and at 915 MHz and 2450 MHz using a test cell and an impedance meter. Dielectric constant increased as temperature increased at both 915 MHz and 2450 MHz. Tomato juice loss factor over the temperature range of 25°C to 121°Cat both 915MHz and 2450 MHz decreased while microwave penetration depth decreased with increasing temperature and frequency. Data gathered in this research could be used for designing industrial scale food sterilization equipment.

KEYWORDS: Depth penetration, Dielectric constant, Food thermal treatment, Loss factor, Magnetron.

INTRODUCTION

Microwave with frequency in the range of (300-300000MHz) are a part of electromagnetic spectrum. Microwave in materials with dielectric properties generates heat through rotation of dipoles. Microwave ovens have been used in households for warming up foodstuffs for decades. In food industry, Microwave equipment have been used for processes like pre-cooking and thawing that has reduced processes time and have also increased food quality in comparison with traditional methods. In the last 20 years, a number of research projects have been done on using microwave in pasteurization, sterilization and drying processes. In microwave processes, heating takes place due to interaction between electromagnetic radiations in specific frequencies with dielectric materials. In contrast with conduction and convection, microwave penetrates the foodstuffs directly and heats the food volumetrically, resulting in energy efficiency and lower heating times[1]. Heating food using microwave is a complicated process which is based on Maxwell equations for electromagnetic waves and food dielectric properties from one side and heat loss which is described by transport phenomena from the other side[2].Microwave frequencies are regulated through specific organizations in the world and for food processing, 915 MHz and 2450 MHz frequencies have been approved by the International Telecommunication Union [3].

When microwave penetrates in foods an interaction between dipole molecules like water and other dipole molecules occurs; water molecules and other polar molecules try to align themselves with the electrical field. Polar molecules attempting to oscillate with such frequencies generate intermolecular friction which in turn produces heat and at the same time a lot of energy is extracted from electric field. Generated heat is propagated in all directions. In the case of fluid foods, the heat is transferred by both conduction and convection methods[4].

The most important factor in microwave heating that presents some information about the mechanism of interaction between electromagnetic energy and materials is dielectric properties. These properties together with other physical properties and properties of materials are characterized in terms of their energy absorption by the materials [5]. Material's Dielectric properties could be defined in relationship with their relative permittivity. Permittivity is a complex number that is used for describing energy absorption from electromagnetic field of a microwave producer, namely; magnetron and is defined as follows[6]:

$$\varepsilon_r = \varepsilon' - j\varepsilon''$$

Where ε_r, ε' and ε'' are relative permittivity, dielectric constant, loss factor and j is corresponding constant, respectively. In the real part, the dielectric constant describes the ability of a material to store energy in response to electric field. The imaginary part; loss factor, describes the ability of a material to dissipate energy in response to an electric field which corresponds to heat generation[7].Rate and volumetric effect of microwave heating is due to penetration of these waves into food. In this regard, dielectric properties could be used for penetration depth determinations. As microwave penetrates into the foodstuff, its power is decreased because some of its energy is absorbed by the food material. The term penetration depth is described as the distance below the surface at which the microwave power level has dropped to e^{-1} of its value[8]. Dielectric properties of food stuffs are dependent on

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temperature and must be determined over the range of temperatures corresponding to pasteurization and sterilization; therefore prediction of heating behavior of dielectric foodstuffs would become possible [9]. Dielectric properties of foodstuffs depend on their constituents and due to complex nature of these constituents, prediction of their dielectric behavior is very difficult, therefore they should be measured for each product individually. The aim of current research is to characterize dielectric constant, loss factor and penetration depth over the temperature range of 25°C-121°C in 915 MHz and 2450 MHz frequencies which in turn would facilitate design of microwave sterilization equipment for tomato juice processing.

Materials and Methods

Dielectric properties measurement system used in this study consisted of a handheld impedance meter from AEA company model Via Echo 1000 and a custom–made test cell. The system has been designed in a manner that has the ability to heat the test cell up to 125°C using an electrical heating element. The whole test cell is radiated by two magnetron each having power equivalent to 3 KW which have been installed at two end of test cell. Dielectric properties measurements were performed on tomato juice. Tomato juice having 8 percent concentration is widely sterilized and packaged in aseptic cartons; it is consumed without further processing by human being. In order to prepare tomato juice, fresh tomatoes (Cultivar Petopride) were purchased directly from Mashhad farms, then they were hand peeled and were crushed. The resulting mixture was passed through a fine filter. Measurements were done on tomato juice every 10°C over the temperature range of 25°C to 125°C.

RESULTS AND DISCUSSIONS

Measured values of dielectric constant and loss factor as a function of temperature and frequency are shown in table 1 and figure 1, respectively.

Table 1-Dielectric properties of tomato juice

Product	Temperature(°C)	915 MHz	2450MHz
Tomato juice	25 ε′	65.6	50.3
	ε′′	34.3	17.5
	35ε′	64.6	49.7
	ε′′	36.1	19.8
	45ε′	62.7	48.1
	ε′′	38.9	21.8
	55ε′	61.5	47.5
	ε′′	42.5	23.7
	65ε′	60.3	46.3
	ε′′	48.9	26.5
	75ε′	59.1	45.7
	ε′′	56.7	30.5
	85ε′	58.8	4
	ε′′	61.1	34.7
	95 ε′	57.1	43.7
	ε′′	68.9	38.7
	105ε′	56.3	42.2
	ε′′	76.8	42.8
	115ε′	55.2	41.1
	ε′′	83.1	47.9
	125ε′	54.1	40.8
	ε′′	90.4	54.8

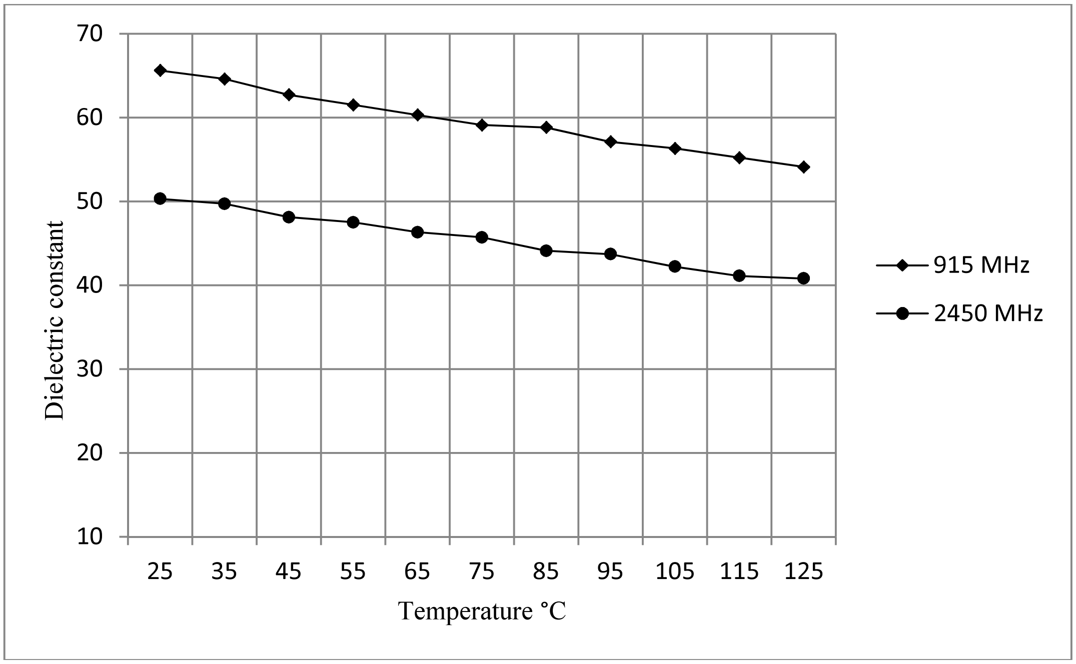

Figure 1-Dielectric constant as a function of temperature at two frequencies; 915 MHz and 2450 MHz

Dielectric constant of tomato juice decreased as temperature increased at both 915 MHz and 2450 MHZ. Dielectric constants of food stuffs are generally more than 80 [10]. Dielectric constant of water is equivalent to 78.2in 25°C and 55.4 in 100°C[11].While foodstuffs typically have more than 80 percent water content, their other constituents also play an important role in determination of dielectric constant. The trend observed in the behavior of dielectric constant is very useful in modeling and design of thermal processing. Tomato juice loss factor increased as temperature increased. Loss factor deals with polar mechanisms including dipoles, electrical and atomic interactions. Loss factor(ε'') is defined as follows:

$$\varepsilon'' = \varepsilon\sigma'' + \varepsilon d''$$

Where $\varepsilon\sigma''$ is relative dipole loss and $\varepsilon d''$ is relative ionic loss. Loss factor contributed by ionic conductivity increases as temperature increases while loss factor contributed by dipole rotation of free water decreases as temperature increases, therefore total loss factor increases with temperature increase. Penetration depth of microwave in 25°C at frequency of 915 MHz was about 13.4 mm which decreased to 4.1 mm as temperature increased to 121°C (Table 2). Likely, penetration depth in 25°C at frequency of 2450 MHZ was about 6.9 mm which decreased to 1.5 mm with increase of temperature over the range of 25°C-121°C. In other words, penetration depth decreased as the frequency increased.

Table 2-Microwave penetration depth as a function of temperature at two frequencies; 915 MHz and 2450 MHz

Product	**Temperature(°C)**	**Penetration Depth(mm)** **915 MHZ**	**2450 MHz**
Tomato juice			
	25	13.4	6.9
	35	12.7	6.3
	45	11.9	5.7
	55	10.5	4.9
	65	9.1	4.5
	75	8.7	4
	85	7.2	3.5
	95	6.4	2.9
	105	5.5	2.4
	115	4.3	1.9
	125	3.9	1.5

Conclusions

Dielectric constant of tomato juice in the range of 25°C-121°C at 915MHz and 2450 MHz frequencies increases. From other side, loss factor of tomato juice over the range of 25°C-121°C at both frequencies of 915 MHz and 2450 MHz decreases and finally, microwave penetration depth decreases as temperature and frequency increases. Data gathered in this study could be used for design of industrial scale microwave sterilizators for sterilization of tomato juice.

REFERENCES

1-Zhu, J., Kuznetsov, A. V., & Sandeep, K. P., 2007. Mathematical modeling of continuous flow microwave heating of liquids (effects of dielectric properties and design parameters). Int. J. Therm Sci, 46: 328–341.

2-Tang, J., Hao, F., & Lau, M., 2002. Microwave heating in food processing. In X. Harrison & J Tang (Eds.), Advances in bioprocessing engineering. pp: 1–44.New York: World Scientific.

3-Singh, R. P., & Heldman, D. R., 2009. Introduction to food engineering (4th ed.). Burlington: Academic Press.

4-Hossan, M. R., Byun, D., & Dutta, P., 2010. Analysis of microwave heating for cylindrical shaped objects. Int. J. Heat Mass Tran., 53: 5129–5138.

5-Nelson, S. O., & Datta, A. K., 2001. Dielectric properties of food materials and electric field interactions. In A. K. Datta & R. C. Anantheswaran (Eds.), Handbook of microwave technology forfood applications (pp. 69–114). New York: Marcel Dekker.

6-Ahmed, J., & Ramaswamy, H. S., 2007. Microwave pasteurization and sterilization of foods. In M. S. Rahman (Ed.), Handbook of food preservation (2nd ed., pp. 691–712). Boca Ratón FL: CRC Press.

7-Wang, Y., & Wang, J. , 2009. Computer simulation of radio frequency heating. In S. Jun & J. M. Irudayaraj (Eds.), Food processing operations modeling (pp. 81–112). Boca Ratón: CRC Press.

8-Yam, K. L., & Lai, C. C., 2006. Microwable frozen food or meals. In Y. H. Hui (Ed.), Handbook of food science, technology and engineering (pp. 113-1–113-8). Boca Ratón: CRC Press.

9- Nelson, S.O., 1991. "Dielectric properties of agricultural products ─ Measurements and Applications." IEEE T Electr Insul., 26(5): 845-869.

10-Sheen, N. I., & Woodhead, I. M., 1999. An open-ended coaxial probe for broad-band permittivity measurement of agricultural products. J Agr Sci., 74:193–202.

11-Hasted, J. B., 1972. Dielectric properties. In F. Franks (Ed.), Water a comprehensive treatise. New York: Plenum Press, pp. 255–309.