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Determination of Mesocarp Mass for Effective Heating in Microwave Assisted Sterilization and Extraction (MASE) of Oil Palm Fruits

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Abstract: ***Determination of palm oil mesocarp mass for effective heating in microwave assisted sterilization and extraction (MASE) was investigated by measuring dielectric properties of the mesocarp. The dielectric properties of oil palm mesocarp were measured using PNA-L Network Analyzer (NA) model N5232A that was equipped with measurement control and data logging. The actual moisture con-tent was determined by standard method oven drying and compared with the predicted value reported by another researcher. Penetration depth (Dp) of the mesocarp which represent how deep the power carried by an electromagnetic wave can penetrate into the material was calculated using an established equation. The results indicated that the dielectric properties of solid surface oil palm mesocarp were comparable to previous research that was obtained at 11.93±4.55 and 4.37±1.62 of dielectric constant and dielectric loss, respectively. The dielectrics constant, ϵ' slurry samples of oil palm mesocarp was measured for 80, 100, and 120g, which represented 56.42±6.61, 52.27±3.76 and 46.86±3.79, respectively. The influence of water in moist mesocarp samples had dielectric properties similar to those of liquid water. Microwave wavelength easily penetrated the sample weight loading at 80g and 100g with Dp of 16mm due to suitable sample bed thickness capable to absorb microwave energy then dissipate heat to the surrounding, which is responsible for the effectiveness in microwave heating.***

Index Terms: ***oil palm mesocarp; bed thickness; dielectric properties, loss tangent; penetration depths.***

I. INTRODUCTION

In palm oil milling, first stage after harvesting that fresh fruit bunches have to undergo is sterilizing process where they have been sterilized in a steam sterilizers. Sterilization process is a critical process to stop formation of free fatty acids (FFA) during pulping process. FFA reduces quality of palm oil and its content has been set by Palm Oil Refiners Association of Malaysia not to be more than 5%. The sterilization process also permits the fruits that are still attached in bunches to be loosened [1]–[3]. In previous work [4], authors reported on an exploratory study of the effect of using various power level, and different ratio of fruit to water, in microwave assisted sterilizer that acquire the shortest time of the fruit to be completely detached from the oil palm fruit spikelet and quality of the oil. The authors have found that the quality of oil is excellent with FFA of crude palm oil below 5%. Therefore, this work presents a detailed study of the extraction of oil palm fruit products using by microwave assisted sterilization and extraction (MASE).

Generally, crude palm oil (CPO) and palm kernel oil (PKO) are the two types of oil palm fruit can produce. The fruit consists of three categories such as an outer epicarp, a middle fibrous mesocarp where oil is extracted and a hard breakable endocarp which shell enclose the kernel. In milling process, the fresh mesocarp of oil palm fruit is extracted to produce high quality of crude palm oil while the kernel is further processing to produce palm kernel oil. Large quantities of waste are generated in the palm oil mill industry. In a traditional extraction of oil by using screw press, about 3% of residual oil per fruit in the fruit fiber still leaves behind which is wasted and oil losses can be quite significant with cumulative amount. Furthermore, a liquid waste known as palm oil mill effluent (POME) was resulted from crude palm oil process.

Over the past decade, claimed have been made in term of good efficiency, extraction time, and solvent consumption throughout introduction and investigation of various extraction technique[5][6]. Microwave assisted extraction specifically has represented significant research attention in various fields, due to its special heating mechanism, moderate capital cost and its good performance under atmospheric conditions. Domestic and industrial microwaves generally operate at 2.45GHz and certain materials can be penetrated and generate heat via interaction with polar components.

In conventional process, usually, throughout external material surface in presence of thermal gradients, heat is transferred to the material by convention, conduction and radiation. Meanwhile, microwave energy is delivered directly through molecular interaction in microwave assisted extraction with thermal energy from electromagnetic energy known as electromagnetic field [7]. Heat created from wave which can penetrate bio materials and interact with polar molecules such as water in the materials from microwave transmitted. [7][8]. Consequently, microwaves can heat the whole material depending on its depth of penetration. Efficiency of microwave heating depends on dissipation factor of the materials represent by loss tangent factor which measures the ability of the sample to absorb microwave energy and distribute heat to the surroundings of molecules.

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Interaction between microwave radiation and the oil palm mesocarp to be heated is mostly a function of the dielectric properties i.e. dielectric constant (ϵ') and dielectric loss factor (ϵ''). ϵ' determines the amount of energy reflected from the product and transmitted into the product while ϵ'' is related to how well a material absorbs energy from electric fields passing through it and how well it converts that energy to heat [9]. Therefore, a good knowledge of thermal and dielectric properties is essential for the design of microwave equipment for food processing and also for an understanding of interaction between products of different formulation and electromagnetic radiation.

Penetration depth is a measurement of how deep electromagnetic radiation can penetrate into a medium or material. The aim of the present study was to determine the appropriate mesocarp mass that formed bed thickness and the thickness plays an important role in depth of penetration of microwave prior to extraction process in MASE. This will lead to an analysis of the distribution of the electromagnetic wavelength that that depends on the geometry of the irradiated object and its dielectric properties, as well as the moisture content.

II. METHODOLOGY

A. Sample preparation

After completing the microwave assisted sterilization [4], the oil palm fruits were cooled down to room temperature. The sterilized oil palm fruits were then subjected to manual peeling from the nut using a stainless-steel blade as depicted in Fig. 1. The sterilization process was conducted at 800W, ratio of fruit to water was 1: 0.5 and for 6min of irradiating time [4]. The peeled off oil palm mesocarp was weighed into 80, 100, and 120g, which represented bed thickness of 30mm, 40mm and 50mm respectively, were placed in a quartz vessel of 100mm in diameter prior to extraction as shown in Fig. 2. In MASE procedure, the oil palm mesocarp was moistened, by soaking the mesocarp in water for one hour, before extraction. The water to mesocarp ratio is 2ml/g. This step was essential to give initial moisture to the peeled off sample which was adapted from [10] prior to MASE method.

Fig. 1: Mesocarp from kernel shell oil palm fruits

B Moisture content m.c measurements

Actual moisture content of the oil palm mesocarps was determined by a standard oven drying method [11]. Before drying, mesocarp sample was weighed using a digital scale and the value was recorded. Next, the mesocarp sample was dried at (103±2) °C in an oven for two to three days, until it reached a constant weight. Relative moisture content (m.c.) of the sample in percentage (wet basis) was calculated by using equation (1):

$$\%\, m.c = \frac{m_{Before\ dry} - m_{After\ dry}}{m_{Before\ dry}} \times 100\% \qquad (1)$$

where $m_{Before\ dry}$ and $m_{After\ dry}$ were weights of the sample before and after drying in the oven, respectively. Relationship between m.c. in the sample and dielectric properties were substantial to determine depth of penetration of wave inside the sample which therefore required an appropriate sample bed thickness to be used in the quartz vessel.

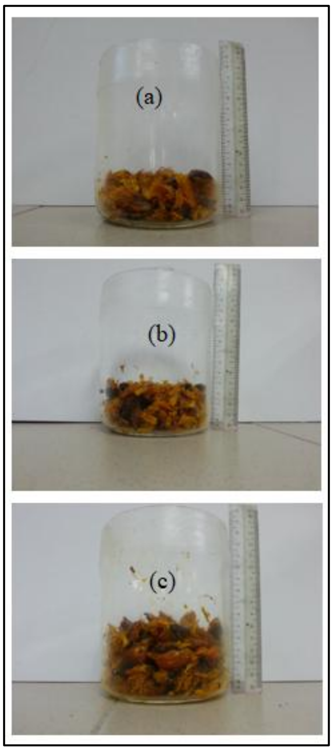


Fig. 2: Oil palm mesocarp with bed thickness of a) 30mm b) 40mm and c) 50mm in a quartz vessel

C Dielectric property measurement

The dielectric property measurements were conducted using PNA-L Network Analyzer (NA) model N5232A, equipped with measurement control and data logging. An open-ended coaxial probe kit software (85070E-02, Agilent); from frequency range of 300kHz to 20GHz was connected to the Network Analyzer. Calibration of the probe was performed using three-point method (water, air and short circuit) at 25°C with system calibration uncertainty below 1%. The probe was attached at the top, used for the calibration and measurements of the samples.

The procedure of dielectric measurement is as follow: after measurement system was calibrated, the measurement was performed at the (1) solid surface while for slurry samples, the probe sensor was immersed into the (2) slurry sample as shown in Fig. 3. Both slurry and solid samples were placed in a 1.0L quartz vessel extraction for MASE method. Averages of five readings were taken at microwave frequency of 2.45GHz for each sample.

A sketch of coaxial probe position during palm oil mesocarp bed thickness test is shown in Fig. 3. Based on [12] studies, dielectric constant ϵ', loss factor ϵ'' and percentage of moisture in mesocarp were correlated with each other. The penetration depth, Dp and loss tangent, tan δ was then determined according to Equation (2) and (3)

$$Dp = \frac{c}{2\pi f\sqrt{2\epsilon'\left[\sqrt{1+\left(\frac{\epsilon''}{\epsilon'}\right)^{2}}-1\right]}} \qquad (2)$$

Where,
c = velocity of light (ms^{-1}),
f = microwave frequency (Hz)

$$\tan\delta = \frac{\epsilon''}{\epsilon'} \qquad (3)$$

Where,
tan δ = loss tangent,
ϵ' = dielectric constant,
ϵ'' = dielectric loss

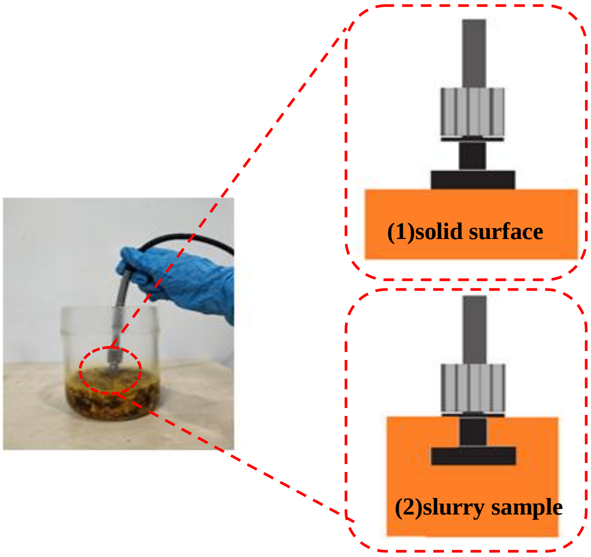


Fig. 3: Open-ended coaxial sensor placed against the surface of the sample. Sketch of coaxial probe position on solid surface and slurry surface

III. RESULTS AND DISCUSSION

A Dielectric properties and penetration depth of solid surface of oil palm mesocarp

Measurement of dielectric properties was compared with the previous study by other researchers to validate the mass selection prior to extraction in MASE. Table 1 indicates the dielectric properties and calculation on depth of penetration of oil palm mesocarp measured at 2.45GHz. This study found that the dielectric property measurement using PNA-L Network Analyzer (NA) gave the depth penetration of 16.31±3.60mm which is slightly higher than the previous study [12][13].

Actual moisture content of the oil palm mesocarp sample is shown in Fig.2, and the standard oven drying method was 33%. Based on the study by Yeow et.al., 2010 [12] they indicated that if the mesocarp moisture content, m.c was within the range of 30-40%, the dielectric constant, ϵ' was within the range of 10-15 these will gave the penetration depth at 16mm. They also claimed that for various percentages of water content m.c. there is a connection between both dielectric constant ϵ' and loss factor ϵ'' of oil palm mesocarp. Subsequently in agriculture, dielectric properties are thought to be primary dependent on water activity and ionic conductivity of fluids surrounded in their cellular structure whereby water content m.c. is the main provider to the value of the dielectric constant of the oil palm mesocarp. In addition, the orientation of water molecules is sensitive to the microwave frequencies, especially at 2.45 GHz. Approximately good agreements are observed between the Yeow et.al., 2010 [12] and Chow and Ma, 2007 [13] results, where their dielectric properties are similar. It can be concluded that the dielectric properties are generally expected to be comparable to previous research.

Table 1: Dielectric properties of solid surface oil palm mesocarp measured at 2450MHz

	Dielectric constant, ϵ'	Dielectric loss, ϵ"	Depth of Penetration, Dp (mm)
Present study	**11.93±4.55**	**4.37±1.62**	**16.31±3.60**
Yeow et.al., 2010 [12]	11.5	4.2	16.0
Chow and Ma, 2007 [13]	11.5	4.2	16.0

B Dielectric properties, loss tangent and penetration depth of the slurry samples oil palm mesocarp

From the preliminary study, it was found that 80-120g was sufficient as bed thickness of the sample to be used in Microwave assisted Sterilization and Extraction (MASE) process. Table 2 shows trends in dielectric properties constant, ϵ' and dielectric loss, ϵ'' measurement from N5232A vector network analyzer (VNA) at the frequency of 2.45GHz conducted at room temperature of 25°C. Generally, it can be observed from Table 2 that both dielectric properties decreased with an increased in mass of mesocarp from 80 to 120g. Similar results were reported by [14] where they claimed that with increasing of mirin (sweet rice wine for seasoning) in Japanese cuisine concentration, the dielectric constant, ϵ' decreased. This is because of its effect on viscosity and ionic conductivity plays an important role on concentration. Furthermore, similar finding was observed from research conducted on sugar solution [15] at different concentrations and they stated that it may be attributed to the exclusion of free water by sugar solutions and stabilization of the hydrogen bonds by the hydroxyl groups.

In this study, the dielectrics measurement was conducted in water to mesocarp ratio of 2ml/g where this ratio is required for efficient microwave heating in MASE. Hence, the sample dielectric constant shows values that are nearly to water dielectric constant [16]. Polar molecules strongly absorb microwave energy because of the permanent dipole moment. Dipole polarization is significant at frequencies above 1GHz. Microwave heating is greatly affected by presence of water in foods as it is a major absorber of microwave energy in the samples.

Table 2: Dielectric properties of slurry sample with ratio of water to mesocarp of 2ml/g

Mesocarp Mass (gram)	Dielectric constant, ϵ'	Dielectric loss, ϵ"
80	56.42±6.61	9.19±0.78
100	52.27±3.76	9.06±0.29
120	46.86±3.79	8.67±0.95

Fig. 4 presents the relationship of penetration depth, Dp with loss tangent, tan δ of mesocarp mass in the quartz vessel extraction. Obviously, the depth of penetration varies inversely with the loss tangent and it is even less when the sample is sensitive to microwaves. The correlation is in good agreement with equation (2). The samples mass affects its ability to absorb microwave energy because it affects molecular rotation. When the molecules are "locked in position" as compact molecules, molecular mobility is reduced, thus making it difficult for the molecules to align with the microwave field. Therefore, the heat produced by dipole rotation decreases since sample contains water, and considering higher dissipation factor (δ) caused faster heat transferred to the water solvent in MASE method. According to [17] it was found that if the loss tangent for the mesocarp layer were high, this means that the mesocarp layer could absorb microwave energy and convert it to heat more quickly.

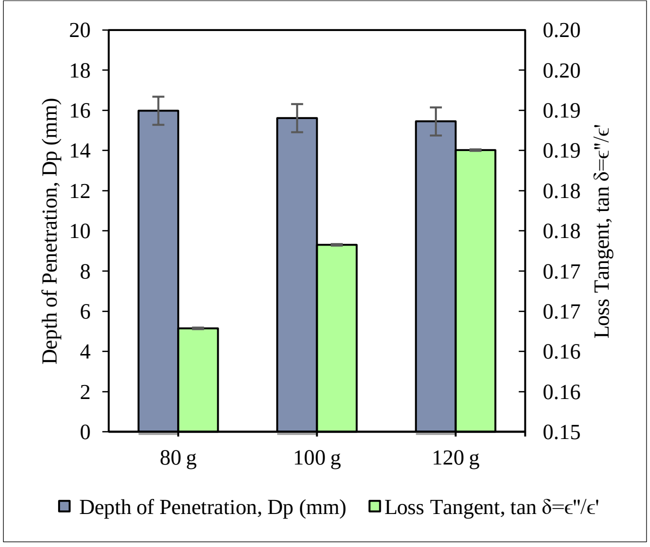
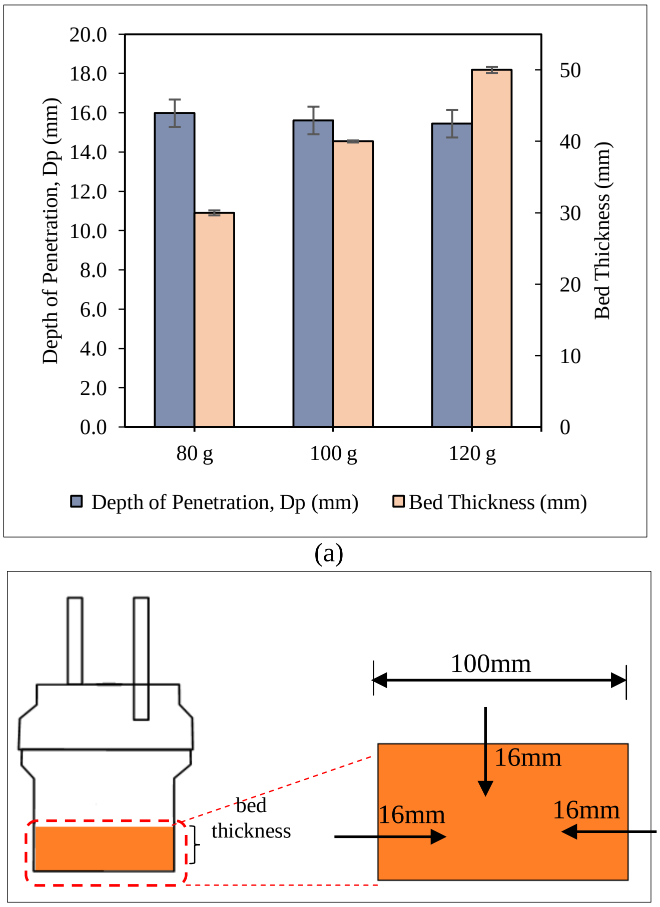


Fig. 4: Penetration depth of mesocarp and loss tangent versus mass of mesocarp in quartz vessel extraction of microwave assisted sterilization and extraction (MASE)

C Analysis on the penetration depth of microwave wavelength on samples

Depth penetration of microwave wavelength to the sample was analyzed by taking the frequency of the microwave used as constant at 2.45GHz. Fig.5(a) shows the depth penetration of the microwave with respect to bed thickness of oil palm mesocarp at water to mesocarp ratio of 2ml/g. In addition, the penetration depth decreased slightly with the increased of bed thickness of oil palm mesocarp samples. Although microwave heating is volumetric and more uniform compared to traditional heating methods, non-uniform temperature inside the sample is one of the major problems associated with the microwave heating that should be avoided if the sample is too thick [18][19]. Because of uneven temperature distribution in MASE quartz vessel extraction, few areas of the material get heated very rapidly, whereas the remaining region gets heated at a lesser extent.

Relationship between depth penetration of microwave wavelength and bed thickness of sample inside the reactor is shown in Fig. 5 (b). For 120g of sample, only few microwave wavelengths can penetrate through the bed. By controlling the bed thickness of oil palm mesocarp in MASE technique, heating distribution could be improved substantially. In this study, it was assumed that wavelength penetration at the side of the reactor was the same, and the difference was only at the sample height i.e bed thickness. Microwave wavelength can penetrate the sample weight loading at 80g and 100g and these weights are suitable to be used for the MASE.



(a)

(b)

Fig. 5: (a) Effect of mesocarp mass on depth penetration and bed thickness. (b) Maximum depth penetration microwave wavelength in the quartz vessel of microwave assisted sterilization and extraction (MASE)

IV. CONCLUSION

Determination of a suitable bed thickness of oil palm mesocarp in MASE technique was needed to guarantee an effective heating distribution and improve microwave wavelength penetration into the sample. Depth of penetration was related to dielectric properties of oil palm mesocarp. It was found that the properties were generally comparable to other researchers which were dielectric constant of 11.93±4.55 and dielectric loss of 4.37±1.62.

The data collected for dielectric properties of solid surface and slurry samples, could be helpful for understanding the heating patterns, cold spots and penetration depths of the oil palm mesocarp. In this study, suitable mesocarp mass were 80g and 100g and penetration depth was 16mm. Further study could be conducted on investigating the factors that influence uniformity of the electromagnetic field which include the shape and size of the product and vessel dimension.

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