EFFECTS OF PARTICLE SHAPES ON TEMPERATURE DISTRIBUTION UNDER STATIC OHMIC HEATING

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BOGOR 2014
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Bogor, January 2014

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ABSTRACT

ANNISA ROHMATIN. Effects of Particle Shapes on Temperature Distribution under Static Ohmic Heating. Supervised by NUGRAHA EDHI SUYATMA, PITIYA KAMONPATANA.

The ohmic heating is defined as a process wherein an alternating electrical current is passed through materials resulting in the heat generation inside the product. The excellence of ohmic heating in comparison with other thermal processing is its energy efficiency and ohmic heating could keeping nutritional as well quality attribute of food via blanching, sterilization, pasteurization, extraction, fermentation, and evaporation. Nevertheless, in ohmic heating process, the electrical conductivity of product is a key parameter. The worst case in the ohmic heating of multiphase product could be occurred when the solid phase has very lower or very high electrical conductivity than the liquid. This study aims to reveal the temperature distribution and the heating rate properties of solid and liquid phase as affected by particle shape and its orientation to the electric field. Experiments were conducted with salt solution 1% and carrot that blanched in salt solution 6%. Blanching process was conducted in order to increase the electrical conductivity of carrot close to the salt solution 1%. Ohmic heating was applied to the sample using static cell (4.90 cm diameter and 6.00 cm in length of sample area) at constant voltage gradient (40 V). Each experiment was conducted in triplicate. It was observed that the different particle shape and orientation provide the different heating rate properties. The slice particle had the fastest heating rate. Moreover the perpendicular orientation was heated faster than parallel orientation. The parallel cylindrical shape provides the slowest heating rate. This shape possibly induced the worst-case condition and could be used as sufficiency heat parameter. The heating pattern of each solid and liquid were simulated using COMSOL modeling software. The predicted temperature values were in good agreement with the experimental data with the maximum prediction error of 3 °C.

Keywords: ohmic heating, electrical conductivity, particle shape, particle orientation
Hak Cipta Milik IPB (Institut Pertanian Bogor)

Bogor Agricultural University
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ANNISA ROHMATIN

Skripsi
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PREFACE

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Bogor, January 2014

Annisa Rohmatin
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INTRODUCTION

Background

The ohmic heating is defined as a process wherein an alternating electrical current is passed through materials (Sastry and Salengke 1998), resulting in the heat generation inside the product (Imai et al. 1995). The excellence of ohmic heating in comparison with other thermal processing is its energy efficiency (close to 100%) (Saltiel and Data 1999). Besides, the ohmic heating can keep nutritional as well quality attributes of food via blanching, sterilization, pasteurization, extraction, fermentation, and evaporation (Parrot 1992).

Electrical conductivity (EC) of food is a key parameter of the electrical properties under ohmic heating (De Alwis and Fryer 1992). The rate of the ohmic heating is directly proportional to the square of the electric field strength and the electrical conductivity (Sastry and Palaniappan 1991). Multi-phase food systems consisting of solid phase and liquid phase, the solid phase can be either heat faster or slower than the liquid depending on its electrical conductivity (De Alwis et al. 1989).

The worst case in the ohmic heating could be occurred when the solid piece has very lower or very high electrical conductivity. The solid piece has the potential to be underprocessed depending on its size and the orientation to electric field (Salengke and Sastry 2007b). Marcotte (1999) classified published data on EC values of solid and liquid foods. Generally, solid vegetable particle have lower EC than the liquid. For maximum process efficiency, blanching treatment have been proposed in the previous study (Sarang et al. 2007).

In the ohmic heating or other heating processes, the concerned things is the uniformity of temperature distribution (Salengke and Sastry 2007a; Shim et al. 2010). Previous study of the ohmic heating (Salengke and Sastry 2007a,b; Shim et al. 2010) evaluated on the necessity of the worst-case condition in the ohmic heating process. In continuous ohmic heating process is not possible to adjust the orientation of the solid particle. In static heater, it is possible to adjust the orientation of particles (De Alwis et al. 1989). A particle orientation study will show which orientation that possibly provide the worst-case condition.

Heating rate in ohmic heating system depends on many factors such as electrical properties, specific heat, particle type, particle size, particle concentration, particle shape, particle orientation in the electric field, and process temperature (De Alwis et al. 1989; Marcotte 1999). De Alwis et al. (1989) studied the effect of particle shape and orientation of a single particle within an ohmic unit system. The previous study were carried out using carrot slice, cylinder, and cubic with varying orientation in order to determine the heating rate with varying liquid electrical conductivity. In the present study, the experiment were carried out using carrot slice, cylindrical, and cubic shape with one kind of liquid electrical conductivity. The slowest heating rate particle can be determined as the worst-case condition in this present study. The particle can be used as the heat efficiency parameter in continuous heating process.
Objectives

Objectives of this study are:

1. To measure the electrical conductivity profile during the ohmic heating (carrot as the solid particle and two kind of percentage salt solution as the liquid) and decide the best sample for the main research.

2. To study the temperature distribution and the heating rate properties of solid and liquid phase as affected by particle shape and orientation to the electric field.

3. To compare the results from the experimental research and the prediction research.

LITERATURE REVIEW

Ohmic Heating

In recent years, minimally processed foods with extended shelf life have much attracted an attention from the food industry due to increase in consumer’s demand for those products. Thermal processing is an option for producing product with extended shelf life. Nevertheless, high temperature in thermal process has a deleterious effect on color, texture, flavor, and nutritional value of food (Knockaert et al. 2011). These drawbacks lead the development of novel food processing methods such as pulsed electric field, pulsed x-ray, microwave heating, ohmic heating (OH), and oscillating magnetic fields (Awuah et al. 2007). Amongst those methods, the OH can keeping nutritional as well quality attribute of food via blanching, sterilization, pasteurization, extraction, and evaporation (Parrot 1992).

The ohmic heating is defined as a process wherein an alternating electrical current is passed through materials (Sastry and Salengke 1998), resulting in the heat generation inside the product (Imai et al. 1995). Electrical energy is converted to thermal energy within a conductor by applying an alternating current across the material. The OH heats materials at extremely rapid rates (Sastry 2005). The main parameter determining the heating rate of the OH treatment is electrical conductivity that usually increases with temperature. The change in the temperature during the OH is very fast and could result in runaway heating in the fluid food if the control is not properly designed (Sastry 2005). For cellular food stuff such as vegetables, the cell membrane is an electrical insulator and current flow is principally confined to the intercellular fluid (Farahnaky et al. 2012).

The benefit of the OH in comparison with other thermal processing is its energy efficiency. The process is closed to 100% energy transfer efficiency in comparison with microwave heating having the energy conversion efficiency 65% at the best (Saltiel and Datta 1999). As a rapid heating method with a more uniform heat distribution than other heating process, the OH is a promising potential technique for food pasteurization and sterilization (Gavahian et al. 2011). Nowadays, the OH is used in various countries (UK, Italy, Mexico) with the commercial scales of several foods (Bozkurt and Icier 2010), pasteurized milk
(Pereira et al. 2008), baby foods (Icier and Ilica 2005), and cooked meat (Bozkurt and Icier 2010; Sarang et al. 2008). The OH was also applied for fruits (Sarang et al. 2008) or vegetables sauces and pasteurized orange juice (Leizerson and Shimoni 2005; Zell et al. 2009). The effect of the OH on product recipes to microbial inactivation and electroporation effect were also developed (Knirsch et al. 2010).

Measurement the Electrical Conductivity

Identical electrical conductivities of fluid and solid particle is important in OH process (De alwis and Fryer 1992; Zareifard 2003). The electrical conductivity relies on the temperature, applied voltage gradient, concentration, and frequency of electrolytes (Icier and Ilicali 2005). The rate of the OH is directly proportional to the square of the electric field strength and the electrical conductivity (Palaniappan and Sastry 1991). In multi-phase food systems that consist of the solid phase and the liquid phase, the solid phase can be either heated faster or slower than that of the liquid depending on its electrical conductivity (De alwis et al. 1989).

Previous studies concerning the electrical conductivity measurement (Marcotte et al. 1999; Zareifard et al. 2003; Sarang et al. 2007; Zhu et al. 2010) evaluated data on the electrical conductivity of the solid and the liquid foods. The electrical conductivity for vegetables was observed lower than the liquid that used as a carrier (Shim et al. 2010). Intact product like raw carrot gives biphased linearly in the electrical conductivity measurement due to starch cellular collapse down by thermal gelatinization (Shim et al. 2010). For maximum process efficiency, blanching treatment have been proposed in the previous study (Sarang et al. 2007).

Worst-case Condition in Ohmic Heating

In the OH or other heating processes, the concern in heating process is about the uniformity of the temperature (Salengke and Sastry 2007; Shim et al. 2010). It is possible that the process of heating is well-going when the coldest point has received a sufficient heat. Previous modeling and experimental work (De Alwis and Fryer 1990; Salengke and Sastry 2007a,b; Shim et al. 2010) stated the necessity to understand regarding the worst-case condition in the OH process. The worst case in the ohmic heating could be occurred when the solid piece has very lower or very high electrical conductivity. The solid piece has the potential to be underprocessed depending on its size and the orientation to electric field (Salengke and Sastry 2007a,b). Knowing the worst-case condition in heating process is necessary regard the determining of sufficient heating parameter.

Particle Shapes Effect

Many factors can affect the heating rate in an OH system: the electrical properties, specific heat, particle type, particle size, particle concentration, the particle shape, particle orientation to the electric field, and process temperature (Marcotte 1999). The previous studies evaluated the numerous of the heating rate
with varying the liquid electrical conductivity, the solid particle shape, and its orientation under static ohmic heating process (De Alwis et al. 1989). The solid particles used in the previous study are carrot and potato in cylinders, cubes, and slices shapes. In all case the cubes displays the lowest heating rate ratio. Regarding the solid particle orientation, the particle located perpendicular to the field heated faster than the liquid. The solid particle heated slower than the liquid while located parallel to the field (De Alwis et al. 1989). Study of the particle shape effect on temperature distribution is essential for knowing the worst-case condition provide among varying shape and orientation.

**METODE**

**Time and Place**

This study was conducted from June 4 to October 4, 2013. Experimental research was done at Food Engineering Laboratorium 2116; modeling research was done at Food Engineering Laboratory 2401 and 2116, Kasetsart University, Bangkok, Thailand.

**Materials and Instruments**

1. **Raw material**
   Carrots were purchased from a local grocery store and cut in different shapes shown in Table 1.

2. **Chemical reagents**
   Reagents for electrical conductivity measurement and for the main research:
   1. Salt solution with NaCl 1% w/w
   2. Salt solution with NaCl 2% w/w
   3. Salt solution with NaCl 6% w/w
   4. Salt solution with NaCl 12% w/w

3. **Equipments and instruments**
   1. T-shape of OH system (figure 1) consisting of:
      - A pair of electrode
      - Thermocouple
      - Sample heating area
      - Spacer
      - Rubber stopper
      - Flange
      - Studs for holding the sample
   2. The ohmic power supply
   3. A data acquisition unit to collect data of voltage, current, and temperature of samples
   4. SPSS 20 Software as statistical instrument (IBM Corp 2011)
Research Stages

The research was carried out in two stages. The first stage was a preliminary included measurement and determination the electrical conductivity of sample. The second stage was main research included determination of particle shape and particle orientation that provide the worst-case condition. The stages of the research can be viewed in Figure 3.
Data Analysis Procedure

Preliminary Research

Measurement of electrical conductivity from carrot

The carrot was cut into cylindrical shapes with volume approximately 13.58 cm³, blanched in boiled salt solution (6% and 12%) for 6 min and then placed inside a small ohmic cell (Figure 3) with constant voltage gradient (17 – 20 V). Each experiment was conducted in triplicate.

Measurement of electrical conductivity from salt solution

Two different concentrations of salt solution (1 and 2 % of NaCl) were evaluated in this measurement. The solution was poured into the small ohmic cell and then measurement was done with constant voltage gradient (17 – 20 V). Each experiment was conducted in triplicate.

Figure 3 A schematic of designed T-shaped small ohmic cell (adapted from Shim et al., 2010)
Determination of electrical conductivity

The electrical conductivity ($\sigma$, S/m) was determined from the resistance of the sample and the geometry of the cell using the following equation (Palaniappan and Sastry 1991):

$$\sigma = \frac{L}{AR} = \frac{LI}{AV} \quad (1)$$

From the preliminary research, it was obtained the graph with temperature as the X-axis and the electrical conductivity as the Y-axis. Palaniappan and Sastry (1991) reported that the electrical conductivity is a linear function of temperature:

$$\sigma = \sigma_0 [1 + mT] \quad (2)$$

From this preliminary research, it was obtained the value of electrical conductivity from carrot and salt solution as temperature dependent.

Main Research

The study of effect particle shapes on temperature distribution during the OH Process

The samples were cut with different shapes and sizes shown in Table 1. There are 5 shapes used in this present study. First shape is a cubic shape. The second is slice shape with large face parallel to the electrical field, in this study this shape was named parallel-slice. The third is slice shape with large face perpendicular to the electrical field; in this study this shape was named perpendicular-slice. The fourth is cylindrical shape with large face perpendicular to the electrical field, in this study this shape was named perpendicular-cylindrical. The fourth is cylindrical shape with large face parallel to the electrical field, in this study this shape was named parallel-cylindrical.

Computational Research using Commercial Software

The temperature distribution will be modeled using commercial software. To verify the model, the fluid and the solid temperature resulted from predicted and experimental research will be compared.
Table 1 The particle shape and their size that used in the main research

<table>
<thead>
<tr>
<th>Front View in Ohmic Cell</th>
<th>The Shapes Figure</th>
<th>The Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>r = 2.3 cm</td>
<td>V = 11.16 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[10.76 % Volume]</td>
</tr>
<tr>
<td></td>
<td>p = 3.5 cm; l=1.3 cm; t=2.5 cm</td>
<td>V = 11.38 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[10.06 % Volume]</td>
</tr>
<tr>
<td></td>
<td>p = 2.5 cm; l=1.3 cm; t=3.5 cm</td>
<td>V = 11.38 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[10.06 % Volume]</td>
</tr>
<tr>
<td></td>
<td>r = 1.1 cm ; t=3 cm</td>
<td>V = 11.41 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[10.08 % Volume]</td>
</tr>
<tr>
<td></td>
<td>r = 1.1 cm ; t=3 cm</td>
<td>V = 11.41 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[10.08 % Volume]</td>
</tr>
</tbody>
</table>

Model development

Similar to the previous studies (Jun and Sastry 2005; Shim et al. 2010), the solid particle used in this study is assumed as single phase material where salt diffusion from the liquid solution would rarely occur. Thus, the ionic concentration of the salt solution is self-sufficient and uniform at any locations. The electrical conductivities of the solid and the liquid samples are temperature dependent and calculated as the following equation (Palaniappan and Sastry 1991):

\[
\sigma = \frac{L}{AR} = \frac{LJ}{AV}
\]  (3)
The temperature distribution within the sample under static OH will be determined by this following equation:

\[ \rho C_p \frac{\partial T}{\partial t} = \nabla (k \nabla T) + S \]  

(4)

Then, the internal energy source \( S \) could be calculated by this following equation:

\[ S = \sigma (T)|\nabla T|^2 \]  

(5)

The initial and boundary conditions developed by the model in 3D are:

\[ T(x, y, z, t) = T_0, \ \forall x, y, z, t = 0 \]  

(6)

Thermal boundary conditions:

\[ k \nabla T(x, y, z, t) \cdot n = 0, \ \forall x, y, z \in \text{[each surface of samples]} \]  

(7)

Electrical boundary conditions:

\[ \psi(x, y, z, t)|_{wall} = 0 \text{ or } V_0, \ \forall t, x, y, z \in \text{[electrode]} \]  

(8)

\[ \mathbf{H}(x, y, z, t)|_{wall} = 0 \text{ or } J_0, \ \forall t, x, y, z \in \text{[each surface of samples]} \]  

(9)

There are five properties unit considered in this work \{thermal conductivity \( k = \text{W/m.K} \); density \( \rho = \text{kg/m}^3 \); specific heat \( C_p = \text{J/kg.K} \); initial electrical conductivity \( \sigma_0 = \text{S/m} \) and temperature coefficient of electrical conductivity \( (m) \} \). The data of thermal conductivity, density, and specific heat for all the food components (ash, fat, fiber, water, and carbohydrate) considered in this work using Choi and Okos model (1986). The model is shown in appendix table 1. The data of initial electrical conductivity and temperature coefficient of electrical conductivity were obtained from preliminary research in the experimental work.

**Model Validation**

Model validation was conducted through comparison the temperature from experimental result and the modeling result by using commercial software. Model was valid when the differences or error between them less than or equal with 3 °C in the end temperature.

**RESULTS AND DISCUSSION**

**Preliminary Research**

Identical electrical conductivities of fluid and solid particle are important in OH process (Lima *et al.* 1999; Zareifard 2003). The most satisfactory the OH occurred in products that have the electrical conductivity in a range of 0.01-10 S/m. Moreover the optimum effectiveness of electrical conductivity is in the range 1 – 5 S/m (De alwis *et al.* 1989 in Zell *et al.* 2009). It has been observed that most vegetables and meats have lower electrical conductivities than liquids (Tulsiyan 2005). In an ohmic heating process for particulate foods, the most desirable situation is the electrical conductivities of fluid and solid particles are equal (Wang and Sastry 1993). In this study, blanching process was conducted for increasing the electrolytic content in the solids. Consequently low-conductivity particles may be made to heat at a similar rate as or faster than the surrounding fluid (Sarang *et al.* 2007).
Electrical conductivity-temperature curve for the solid and liquid particle are shown in figure 5. Y-error bars shown are the double standard deviation. The electrical conductivity data are also summary for selected temperature in table 2. For all samples, the electrical conductivity increase linearly with temperature. This result is suitable and consistence with the literature data (Palaniappan and Sastry 1991).

On the other hand, figure 5 provide an electrical conductivity equation for each sample. The electrical conductivity is a linear function of temperature like this following equation:

$$\sigma = \sigma_0 + (\sigma_0 m)T$$

(10)
It can be obtained the $\sigma_0$ and m value from the each graph. Salt solution 2% provide -10.95 as $\sigma_0$ and 0.00429 as m value. While salt solution 1% presents -6.434 as $\sigma_0$ and 0.0042 as m value. The $\sigma_0$ value for carrot that blanched in 12 % salt solution is -14.69 with the m value is 0.00381. Meanwhile, the carrot that blanched in 6% salt solution provide -6.603 as the $\sigma_0$ value and 0.00379 as m value.

The higher value group which consist of salt solution 2% as the liquid and carrot that blanched in salt solution 12% provide the value of $\sigma_0$ for salt solution is less than carrot but they show the same m value. For the other group, both of $\sigma_0$ and m value for the salt is more than the carrot. Nevertheless the gap between their linear graphs is close and the linear graph of carrot always below the salt solution. This is contrary with the salt solution 2 % group due to the graph of carrot become above the salt solution after 400°K. This result become the reason to select the salt solution 1% and the carrot that blanched in salt solution 6% as the sample for the main research.

Figure 5 presents the salt solution 2% has the highest value of the electrical conductivity. Nevertheless the standard deviation of salt solution 2% measurement is higher than salt solution 1%. Besides that the standard deviation of carrot that blanched in salt solution 12% is higher than carrot that blanched in salt solution 6%. Moreover the blanching in salt solution 12% will provide more soft carrot than salt solution 6%. The soft carrot is quite hard to handle due to itsbrittleness and easily damaged. Regarding that result, salt solution 1% and carrot that blanched in salt solution 6% is selected as the sample in the main research.

Main Research

Effect of Particle Shape

Heating rate in ohmic heating system depends on many factors such as electrical properties, specific heat, particle type, particle size, particle concentration, particle shape, particle orientation in the electric field, and process temperature (De Alwis et al. 1989; Marcotte 1999). The physical properties of solid particle are influenced by the particle shape and particle size (Qiang et al. 2012). Figure 6 presents the heating profile within the solid particle was quite uniform for cubic and parallel slice particle. For raising the same temperature (80°C) perpendicular slice provide the fastest time (230 second). The cubic shape and the parallel slice shape as the second (around 270 second). The perpendicular cylindrical shape is the third (285 second). The parallel cylindrical provide the slowest heating rate (300 second).

Concerning the effect of particle shape could be seen that the slice shape has faster heating rate than the cubic. The cylindrical particle has the slowest heating rate. Every particle shape has different ratio surface area per unit volume, different surface area, different resistance bulk value, and different cross-sectional area to the electric field. These things could be responsible to the result. Table 5 presents the cylindrical has the smallest value of ratio surface area that heated per unit volume. Experimental result show the cylindrical shape has the slowest heating rate compared with the other shape. The slice has the highest value of the
ratio and experimental shows the slice shape has the fastest heating rate. According to the previous study (De Alwis et al. 1989) stated that the thinner particle will be heating faster. The thinner particle or the particle that has higher ratio of surface area per unit volume will have the wider area for heated. Figure 8 and 9 present the correlation between surface area (A) and ratio surface area per unit volume (A/V) to the temperature at 240 s.

![Figure 6 Heating rate properties within solid particle in different shape and orientation](image)

![Figure 7 Heating rate properties within liquid particle](image)

<table>
<thead>
<tr>
<th>Time</th>
<th>Cubic-shape</th>
<th>Parallel-slice shape</th>
<th>Perpendicular-slice shape</th>
<th>Parallel-Cylindrical shape</th>
<th>Perpendicular-Cylindrical shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27.13 ± 0.55a</td>
<td>27.30 ± 0.60a</td>
<td>27.17 ± 0.71a</td>
<td>27.13 ± 0.15a</td>
<td>25.70 ± 0.87a</td>
</tr>
<tr>
<td>40</td>
<td>33.07 ± 0.15b</td>
<td>32.70 ± 1.35b</td>
<td>35.33 ± 0.45c</td>
<td>31.63 ± 0.70ab</td>
<td>31.33 ± 0.64a</td>
</tr>
<tr>
<td>80</td>
<td>40.17 ± 0.51b</td>
<td>39.90 ± 1.95b</td>
<td>44.63 ± 0.35c</td>
<td>37.63 ± 1.11a</td>
<td>38.47 ± 2.67ab</td>
</tr>
<tr>
<td>120</td>
<td>58.10 ± 0.87b</td>
<td>48.00 ± 1.41b</td>
<td>54.27 ± 0.15c</td>
<td>44.60 ± 1.31a</td>
<td>46.33 ± 0.50ab</td>
</tr>
<tr>
<td>160</td>
<td>60.50 ± 0.87d</td>
<td>56.27 ± 0.75c</td>
<td>63.46 ± 0.15c</td>
<td>52.03 ± 1.12a</td>
<td>54.10 ± 0.26b</td>
</tr>
<tr>
<td>200</td>
<td>64.60 ± 0.87c</td>
<td>64.20 ± 0.61c</td>
<td>72.46 ± 0.32d</td>
<td>59.57 ± 0.85d</td>
<td>61.93 ± 0.38b</td>
</tr>
<tr>
<td>240</td>
<td>72.67 ± 0.76c</td>
<td>72.17 ± 0.90c</td>
<td>81.20 ± 0.61d</td>
<td>67.27 ± 0.58c</td>
<td>69.83 ± 0.65b</td>
</tr>
</tbody>
</table>

**A** Average of 3 sample values (±std. dev.)

**a-e** Mean value in the same row with the same letter are not significantly different (p>0.05 for α=0.05)
Table 4 Temperature result within liquid particle in different time heating process

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Cubic-shape</th>
<th>Parallel-slice shape</th>
<th>Perpendicular-slice shape</th>
<th>Parallel-Cylindrical shape</th>
<th>Perpendicular-Cylindrical shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27.40 ± 0.70&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>28.07 ± 0.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.70 ± 0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.60 ± 0.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>27.47 ± 0.83&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>36.23 ± 0.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.00 ± 2.15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.03 ± 1.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.87 ± 0.64&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.13 ± 0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>42.93 ± 0.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42.23 ± 1.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.90 ± 1.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.97 ± 0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42.17 ± 1.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>48.67 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.43 ± 1.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.70 ± 1.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>49.93 ± 0.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47.83 ± 0.99&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>53.87 ± 0.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54.16 ± 1.26&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>54.47 ± 0.91&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>55.77 ± 0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>53.83 ± 1.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>60</td>
<td>59.50 ± 0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>60.40 ± 1.25&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>57.43 ± 0.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>61.63 ± 0.50&lt;sup&gt;c&lt;/sup&gt;</td>
<td>59.63 ± 1.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0</td>
<td>65.57 ± 0.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66.73 ± 1.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66.93 ± 0.66&lt;sup&gt;a&lt;/sup&gt;</td>
<td>67.87 ± 0.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>65.97 ± 1.32&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Mean value in the same row with the same letter are not significantly different (p>0.05 for α=0.05).

Average of 3 sample values (± std. dev.)

Figure 8 presents the correlation between surface area and temperature of solid. The statistical result provides the significant correlation between surface area and temperature. The statistical result present the correlation equation between them is $y = 1.527x + 27.695$ with $r^2 = 0.394$. Figure 9 shows the correlation between ratio of surface area per unit volume and temperature of solid. The statistical result present the significant correlation between them with the equation is $y = 0.18x + 23.098$ ($r^2=0.623$). From the result, it could be seen that the bigger ratio of surface area per unit volume will provide the faster heating rate in solid particle. Moreover, from figure 8 it could be seen that bigger of surface area will provide the faster heating rate. Concerning the shape effect, slice has the widest surface area so that this shape provides the fastest heating rate. Contrary, the cylindrical shape provides the slowest heating rate due to its smallest surface area.

![Figure 8 Corelation curve between Surface Area and Temperature of solid at 240 seconds](image-url)
Figure 9 Corelation curve between Ratio of Surface Area per unit Volume and Temperature of solid at 240 seconds

Table 5 Ratio Surface Area per unit volume within three shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>Surface Area (A)</th>
<th>Volume (V)</th>
<th>Ratio Surface Area per unit Volume (A/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic</td>
<td>$2.91 \times 10^{-3}$</td>
<td>$1.07 \times 10^{-5}$</td>
<td>272.69$^b$</td>
</tr>
<tr>
<td>Slice</td>
<td>$3.15 \times 10^{-3}$</td>
<td>$1.05 \times 10^{-5}$</td>
<td>299.09$^a$</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>$2.74 \times 10^{-3}$</td>
<td>$1.08 \times 10^{-5}$</td>
<td>253.51$^c$</td>
</tr>
</tbody>
</table>

$^a$Mean value in the same column with the same letter are not significantly different (p>0.05)

Average data from triplicate for each sample shape

The simulation work by modeling software was conducted to study the temperature distribution within the sample. Figure 10 and 11 compare the predicted heating pattern of the liquid and solid with the experimental result in preliminary research. Figure 10 and 11 present the heating time for raising the temperature 80°C for the solid and liquid when the measurement conduct...
separately is around 120 until 180 second. Due to the main research when the measurement conduct in mixture particle the heating time that needed for heat the particle until the same temperature (80°C) is around 240 until 300 second (figure 6).

The result provides the difference that occurred in one particle heating (just solid or liquid) and mixture particle (solid and liquid). Mixture particle provide longer time than the individually particle. Besides, this difference could be explained due to the difference equipment that used. In the preliminary research the experimental conduct with the small equipment. However the main research conducts with the bigger equipment. This difference could be solved by the correction factor.

![Figure 11 Comparison of predicted heating patterns of solid with their experimental measurements](image)

**Effects of Particle orientation**

Particle orientation will provide the significant effect on the heating properties of material under ohmic heating (De Alwis et al. 1989; Zareifard et al. 2003). Heat generated in a material can be changed by changing the current flow or the bulk resistance (De Alwis et al. 1989). The different shape and orientation has the different bulk resistance properties. Besides, the different shape and orientation will provide different cross-sectional area perpendicular to the electric field. De Alwis et al (1989) studied the effect of particle shape and orientation of single particle. In this previous study used two kind solid particles, the solid particle with lower electrical conductivity than the liquid and the solid particle with higher electrical conductivity than the liquid. In the present study, the solid particle has the electrical conductivity that close with the liquid.

Regarding the previous study, De Alwis et al (1989) stated that for the mixture particle that has liquid electrical conductivity bigger than the solid for maximize the heat generation the bulk resistance ratio should be minimize. In this present study, electrical conductivity of liquid is higher than the solid. This means in this present study, the smaller resistance bulk ratio will provide the higher heating rate properties. Therefore the parallel shapes that have bigger value of resistance bulk will heat slower than the perpendicular shape.
Figure 12 shows that the solid particle heating faster when perpendicular to the field. Moreover for every shape, the perpendicular orientation provide faster heating rate than the parallel. Figure 13 present the correlation between resistance bulk and heating rate the solid particle with different shapes and orientation. The
This statistical result provides the significant negative correlation between them. This result is suitable with the theory. According to the theory the smallest resistance bulk value is perpendicular slice (table 6). Due to that point, the perpendicular slice shape will be heating faster than the other shape. According to the result we could conclude that the different particle shape will provide the different heating rate properties. The heating rate properties rely on the ratio of surface per unit volume and the resistance bulk ratio. Consequently we still have to concern with the effect of particle orientation beside the effect of particle shape (Zareifard et al. 2003).

Table 6 Resistance bulk value within five treatment solid particles

<table>
<thead>
<tr>
<th>Shape</th>
<th>Orientation</th>
<th>Length parallel to the electric field (L)</th>
<th>Cross-sectional area perpendicular to the electric field (A)</th>
<th>Resistance Bulk (L/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic</td>
<td>-</td>
<td>2.21x10^2</td>
<td>4.82x10^-4</td>
<td>46.07^c</td>
</tr>
<tr>
<td>Slice Parallel</td>
<td></td>
<td>3.47x10^2</td>
<td>3.08x10^-4</td>
<td>112.74^c</td>
</tr>
<tr>
<td>Slice Perpendicular</td>
<td></td>
<td>1.26x10^2</td>
<td>8.20x10^-4</td>
<td>15.42^a</td>
</tr>
<tr>
<td>Cylindrical Parallel</td>
<td></td>
<td>3.03x10^2</td>
<td>3.67x10^-4</td>
<td>82.36^d</td>
</tr>
<tr>
<td>Cylindrical Perpendicular</td>
<td></td>
<td>2.12x10^2</td>
<td>5.22x10^-4</td>
<td>40.59^b</td>
</tr>
</tbody>
</table>

Mean value in the same column with the same letter are not significantly different (p>0.05)

Figure 13 Correlation curve between resistance bulk (L/A) and temperature within 5 shapes treatment

Besides the resistance bulk value, the cross-sectional area perpendicular to the electric field will provide the correlation with the heating rate. This following table and figure present the correlation between cross-sectional area perpendicular to the electric field and temperature.

Figure 12 present that there is a small difference was observed between the temperature of the two phases at the beginning of heating and the deviation...
increased with the time. Moreover figure 12 shows that generally the solid particle has the faster heating rate than the liquid (dT_s > dT_l). This result provides the ratio heating rate (R_T) between solid (dT_s) and liquid (dT_l) more than 1 (R_T > 1). The heating rate ratio data was shown in appendix 2. However, the solid has the lower electrical conductivity than the liquid. The explanation regarding this result will provide in the next paragraph. Figure 14 shows the positive correlation within temperature and cross-sectional area perpendicular to the electric field. It could be seen that bigger cross-sectional area to the electric field will provide higher temperature or faster heating rate. Meanwhile figure 15 presents the correlation within heating ratio (R_T = dT_s / dT_l) and cross-sectional area perpendicular to the electric field. From the figure 15 could be seen that the slice perpendicular that has the biggest cross-sectional area perpendicular to the electric field provide the biggest heating ratio.

Table 7: Cross-sectional area perpendicular to the electric field

<table>
<thead>
<tr>
<th>Shape</th>
<th>Orientation</th>
<th>Cross-sectional Area Perpendicular to the Electric Field (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic</td>
<td>-</td>
<td>Replicate 1 4.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 2 4.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 3 4.73</td>
</tr>
<tr>
<td>Slice</td>
<td>Parallel</td>
<td>Replicate 1 2.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 2 3.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 3 3.12</td>
</tr>
<tr>
<td>Slice</td>
<td>Perpendicular</td>
<td>Replicate 1 8.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 2 8.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 3 7.88</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>Parallel</td>
<td>Replicate 1 3.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 2 3.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 3 3.63</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>Perpendicular</td>
<td>Replicate 1 4.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 2 4.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicate 3 5.06</td>
</tr>
</tbody>
</table>

Figure 14: Correlation curve between cross-sectional area perpendicular to the electric field and temperature at 240 seconds
The modeling work was conducted to explain this result. Previous study (Salengke and Sastry 2007) reported that for static model is generally conservative when the cold spot is within the medium. The cold zone is within the medium at shadow zone immediately in front/back of the particle when the solid particle becomes sufficiently large to intercept a large fraction of the current. In this study, two thermocouples were placed in the middle of solid piece and the liquid near the solid. The places were predicted as the coldest point within the mixture particle.

The modeling results explain regard the thermocouple that placed in the medium near the solid particle (at the back side of solid). The thermocouple was placed in cold zone area. This area becomes a shadow zone from the solid temperature. In the other hand, the medium temperature outside the shadow area was higher than the solid according to their electrical conductivity. The modeling result shows clearly the differences between the medium temperature in the shadow area and the outside. This shadow effect provides the higher influence in perpendicular orientation than parallel. Moreover the shadows effect provides the higher influence in slice than the other shape. It could be seen in figure 12, the end temperature for slice perpendicular provide the big gap between temperature of solid and liquid. Contrary in cylindrical parallel the end temperature between both of them is so close. The cross-sectional area perpendicular to the field is the reason for the difference influence of shadow-effect in the result. Due to the area that provided in intercept the fraction of the current. Unfortunately, the modeling results that show the shadow zone effect cannot be provided in this paper regard the copyright of commercial software.

It is really important for knowing the shadow effect in heating process besides the heating rate. In this present study, slice perpendicular show the highest heating rate while the shadow effect provide a large influence to this shape. In this present study, the shadow effect provides the cold zone in medium although the medium has higher electrical conductivity than the solid. Nevertheless the cold zone in medium is not significantly different between five shapes in the end of process (shown in table 4).
CONCLUSION AND RECOMMENDATION

Conclusion

The electrical conductivity from carrot and salt solution 1% were determined. The heating rate and heat distribution were studied. Electrical conductivities were found increase linearly with temperature increase. Particle shape and orientation were found influence to the heating rate properties of two-phase particle. The slice shape was providing the fastest heating rate between the other shapes. The cylindrical was providing the slowest heating rate. The ratio of surface area heated per unit volume and surface area were the reason for the previous result. The perpendicular orientation was providing the faster heating rate than the parallel orientation. Due to the resistance bulk of perpendicular material is less than the parallel. Moreover the cross-sectional area perpendicular to the electric of perpendicular shape is bigger than the parallel. Consequently the perpendicular slice shape was providing the fastest heating rate and heat distribution among the treatment shapes. On the other hand the parallel cylindrical was possibly become the worst-case condition under ohmic heating. Regarding the result, the parallel cylindrical could be determined as the heat sufficiency parameter under the continuous ohmic heating process. Nevertheless, it still has to consider regarding the shadow effect that can affect much in perpendicular orientation.

Recommendation

1. Further study is needed to investigate the mechanism in shadow effect surrounding the solid sample.
2. The amount of thermocouple should be added for better describing the real condition within the samples.
3. The application in continuous ohmic heating process are needed to evaluate this study result.

REFERENCES


APPENDIXES

Appendix 1 Table of Choi and Okos Models (1986) in Sing and Heldman (2009)

<table>
<thead>
<tr>
<th>Choi and Okos Models</th>
<th>Present Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivities (W/(m.K))</td>
<td>(R²)</td>
</tr>
<tr>
<td>k laughter = 1.7881 x 10⁻¹ + 1.958 x 10⁻¹ - 2.7178 x 10⁻⁸Z²</td>
<td>k laughter = 0.1742 exp(0.0069t)</td>
</tr>
<tr>
<td>k fat = 1.8071 x 10⁻¹ - 2.7604 x 10⁻¹ - 1.7749 x 10⁻⁸Z²</td>
<td>k fat = 0.1647 exp(-0.0171t)</td>
</tr>
<tr>
<td>k cabo = 2.0141 x 10⁻¹ + 1.3874 x 10⁻¹ - 4.3312 x 10⁻⁸Z²</td>
<td>k cabo = 0.1951 exp(0.0072t)</td>
</tr>
<tr>
<td>k fib = 1.8331 x 10⁻¹ + 1.2497 x 10⁻¹ - 3.1683 x 10⁻⁸Z²</td>
<td>k fib = 0.1782 exp(0.0071t)</td>
</tr>
<tr>
<td>k ash = 3.2962 x 10⁻¹ + 1.4011 x 10⁻¹ - 2.9069 x 10⁻⁸Z²</td>
<td>k ash = 0.04t + 0.3277</td>
</tr>
</tbody>
</table>

Thermal Diffusivity (m²/s)

| k fat = 9.8777 x 10⁻⁴ + 4.7578 x 10⁻¹ - 1.4646 x 10⁻¹Z² | k fat = 7 x 10⁻⁸ exp(0.0073t) | 0.9771 |
| k cabo = 8.0842 x 10⁻¹ + 5.3052 x 10⁻¹ - 2.3218 x 10⁻¹Z² | k cabo = 8 x 10⁻⁸ exp(0.0069t) | 0.9691 |
| k fib = 7.3976 x 10⁻¹ + 5 1902 x 10⁻¹ - 2.2202 x 10⁻¹Z² | k fib = 7 x 10⁻⁸ exp(0.0074t) | 0.9883 |
| k ash = 1.2461 x 10⁻¹ + 3.7321 x 10⁻¹ - 1.2244 x 10⁻¹Z² | k ash = 1 x 10⁻⁸ exp(0.003t) | 0.9883 |

Density (kg/m³)

| k fat = 9.2559 x 10⁻¹ - 4.1757 x 10⁻¹ | k fat = 925.53 exp(-0.0005t) | 1.000 |
| k cabo = 1.5991 x 10⁻¹ - 3.1046 x 10⁻¹ | k cabo = 1599.1 exp(0.0002t) | 1.000 |
| k fib = 1.3115 x 10⁻¹ - 3.6589 x 10⁻¹ | k fib = 1311.5 exp(-0.0003t) | 1.000 |
| k ash = 2.4238 x 10⁻¹ - 2.8063 x 10⁻¹ | k ash = 2423.8 exp(-0.0011t) | 1.000 |

Specific Heat (KJ/kg.K)

| k fat = 2.0082 + 1.2089 x 10⁻¹ - 1.3129 x 10⁻¹Z² | k fat = 2.0071 exp(0.0006t) | 0.999 |
| k cabo = 1.9842 + 1.4733 x 10⁻¹ - 4.8008 x 10⁻¹Z² | k cabo = 1.9806 exp(-0.0007t) | 0.9933 |
| k fib = 1.8459 + 1.8306 x 10⁻¹ - 4.6590 x 10⁻¹Z² | k fib = 1.8422 exp(-0.001t) | 0.9953 |
| k ash = 1.0926 + 1.8896 x 10⁻¹ - 4.6817 x 10⁻¹Z² | k ash = 1.089 exp(0.0017t) | 0.9959 |

Appendix 2 Table of Heat Ratio within five shapes treatment

<table>
<thead>
<tr>
<th>Shape</th>
<th>Solid</th>
<th>Liquid</th>
<th>Heating Ratio / Rf (dTds/dTs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ts initial</td>
<td>T 240</td>
<td>T 240</td>
</tr>
<tr>
<td>Cubic</td>
<td>26.6</td>
<td>73.0</td>
<td>46.4</td>
</tr>
<tr>
<td></td>
<td>27.1</td>
<td>73.2</td>
<td>46.1</td>
</tr>
<tr>
<td></td>
<td>27.7</td>
<td>71.8</td>
<td>44.1</td>
</tr>
<tr>
<td>Slice parallel</td>
<td>27.9</td>
<td>71.3</td>
<td>43.4</td>
</tr>
<tr>
<td></td>
<td>27.3</td>
<td>72.1</td>
<td>44.8</td>
</tr>
<tr>
<td></td>
<td>26.7</td>
<td>73.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Slice</td>
<td>27.8</td>
<td>81.6</td>
<td>53.8</td>
</tr>
<tr>
<td>Perpendicular</td>
<td>26.4</td>
<td>81.5</td>
<td>55.1</td>
</tr>
<tr>
<td></td>
<td>27.3</td>
<td>80.5</td>
<td>53.2</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>27.1</td>
<td>67.5</td>
<td>40.4</td>
</tr>
<tr>
<td>Parallel</td>
<td>27.0</td>
<td>66.6</td>
<td>39.6</td>
</tr>
<tr>
<td></td>
<td>27.3</td>
<td>67.7</td>
<td>40.4</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>26.7</td>
<td>69.2</td>
<td>42.5</td>
</tr>
<tr>
<td>Perpendicular</td>
<td>25.1</td>
<td>69.8</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>25.3</td>
<td>70.5</td>
<td>45.2</td>
</tr>
</tbody>
</table>
### Appendix 3 Table of Surface area, Ratio area per unit volume, and Cross sectional area perpendicular to the field within 5 shapes

<table>
<thead>
<tr>
<th>Shape and orientation</th>
<th>Temperature of solid</th>
<th>Surface Area</th>
<th>Ratio of Surface Area per unit volume</th>
<th>Cross sectional Area Perpendicular to the field</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cubic</strong></td>
<td>73.0</td>
<td>29.49</td>
<td>270.75</td>
<td>4.84</td>
</tr>
<tr>
<td></td>
<td>73.2</td>
<td>29.05</td>
<td>271.92</td>
<td>4.87</td>
</tr>
<tr>
<td></td>
<td>71.8</td>
<td>29.72</td>
<td>274.39</td>
<td>4.73</td>
</tr>
<tr>
<td><strong>Parallel Slice</strong></td>
<td>71.3</td>
<td>31.19</td>
<td>301.80</td>
<td>2.95</td>
</tr>
<tr>
<td></td>
<td>72.1</td>
<td>32.12</td>
<td>295.66</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td>73.1</td>
<td>32.14</td>
<td>295.16</td>
<td>3.12</td>
</tr>
<tr>
<td><strong>Perpendicular Slice</strong></td>
<td>81.6</td>
<td>32.03</td>
<td>294.08</td>
<td>8.38</td>
</tr>
<tr>
<td></td>
<td>81.5</td>
<td>30.89</td>
<td>305.60</td>
<td>8.34</td>
</tr>
<tr>
<td></td>
<td>80.5</td>
<td>30.35</td>
<td>302.21</td>
<td>7.88</td>
</tr>
<tr>
<td><strong>Parallel Cylindrical</strong></td>
<td>67.5</td>
<td>28.19</td>
<td>250.56</td>
<td>3.63</td>
</tr>
<tr>
<td></td>
<td>66.6</td>
<td>28.33</td>
<td>248.48</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>67.7</td>
<td>27.51</td>
<td>252.71</td>
<td>3.63</td>
</tr>
<tr>
<td><strong>Perpendicular Cylindrical</strong></td>
<td>69.2</td>
<td>26.05</td>
<td>259.44</td>
<td>4.78</td>
</tr>
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VITAE

Annisa Rohmatin was born in Bogor, West Java, August 9, 1992. She is the eldest child of Mr. Muhammad Yusuf and Mrs. Syamsidar. She had her kindergarten in Daarul Istiqoomah, Bogor (1996-1998) and continued her elementary school, junior high school, and senior high school in SDN Cileunsi 6 (1998-2004), SLTPN 1 Cileunsi (2004-2007), and SMAN 3 Bogor (2007-2009). In 2009, the author continued her study in Bogor Agricultural University. She was accepted as a Food Science and Technology student in the Faculty of Agricultural Engineering and Technology.

During her study, the author was granted the scholarship from ASTAGA scholarship (2009), POM IPB (2009 - 2010), and Tanoto Foundation (2010 – 2013). Besides, she joined some organizations actively, such as HIMITEPA and trusted as monitoring staff. She joined EMULSI magazine as marketing staff. She joined BEM FATETA 2012 as canteen management staff. The author joined some committee actively, such as PLASMA (Pelatihan Pangan Halal), HACCP (Hazard Critical Control Point), LCTIP (Lomba Cepat Tepat Ilmu Pangan), BAUR 2011, and TECHNO-F 2011. Gratefully, she was granted a partial scholarship in AIMS (Asian International Mobility for Student) program to do research on Food Science and Technology, Agro-Industry Faculty, Kasetsart University, for 4 months. In June 2013, she started her research entitled “Effects of Particle Shapes Temperature Distribution under Static Ohmic Heating” with Ajarn Pitiya Kamonpatana, Ph.D as advisor in Kasetsart University and Mr. Nugraha Edhi Suyatma, STP, DEA as her academic advisor in Bogor Agricultural University.