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Preliminary Study of Heat Distribution in Sweet Potatoes Heated by Microwave

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Abstract. Electromagnetic wave can directly affect temperature generation and distribution in foodstuff heated by microwave oven. The heat distribution of sweet potatoes temporally takes many forms using the domestic microwave oven with a single source of micro wave 2.45 GHz. The treatment of food using microwave oven is largely consentrated on the dielectric properties of foodstuff. This study aims to simulate the distribution of heat in sweet potatoes in a microwave oven with various geometric shapes and sizes. The shape of the sample used in this research is sphere and cylindrical. Heat distribution modeling on a microwave oven uses finite element method as a support for the study. The effects of the shape and size of the sweet potato is very influential on the heat distribution that occurs in the sweet potato sample. The influence of the shape and size of the sweet potato is due to the large penetration depth of the sweet potato so that the microwaves absorbed by the sweet potato depend on the thickness and shape of the sweet potato. The conduct simulation was showing the heating process using the microwave did not spread from the sample surface to inside the sample yet from the midpoint caused by the microwave conversion to the heat. Afterwards, it spreads to the surface subsequently after the microwave has passed the depth of penetration of the sample. The spherical shape has a very fast temperature rise compared to the cylindrical shape. The sphere with a radius of 42 mm took time 60 seconds for the heat in the sample to reach 100^0 C with almost equal heat distribution.

INTRODUCTION

The process of cooking food ingredients is by heating the food ingredients, either using conventional methods or by using microwaves. Heating with microwaves as a form of electromagnetic waves has many advantages over conventional heating. The use of microwaves will increase the higher heating efficiency, result in better uniformity of maturity, easier control of the heating process, easier equipment maintenance and a more environmentally friendly heating process. The short heating time duration and volumetric heating are also advantages of microwave heating [1]. A domestic microwave oven is a household appliance that uses microwaves that are directed at the heating room. Heating in a Microwave Oven does not occur due to a temperature gradient but through the propagation of electromagnetic waves [2]. Electromagnetic wave frequencies that qualify as microwaves are in the range of 0.3 GHz to 300 GHz or at wavelengths in the range of 0.001 m to 1 m. Most of the domestic microwave ovens designed for the heating of foodstuffs operate at a frequency of 2.45 GHz [3].

Studies on the use of microwaves in microwave ovens are mostly concentrated on two aspects, namely factors that affect dielectric properties and factors that affect the structure of Microwave Oven equipment. The first aspect that is predominantly correlated with dielectric properties is the shape effect and the deformation effect of the material, while the second aspect is related to the structure of the equipment, namely microwave properties, Microwave Oven processing strategy and experimental procedures [4]. The heat distribution is related to the dielectric properties of the material and the dielectric properties are determined by the form factor of the food material [5]. The dielectric property of food materials is called electric permittivity consists of two components, namely a real component called the dielectric coefficient and an imaginary component called the dielectric loss factor. This dielectric property can be used to characterize the ability to store electromagnetic energy and the ability to convert electromagnetic energy into heat in food materials [6].

Heat distribution in food ingredients can be studied by building a model of heat distribution via electromagnetic distribution that occurs during the heating process in a Microwave Oven [7]. The computational heat distribution simulation is an efficient method to study the interaction of dielectric properties of food ingredients which are influenced by the shape of the material with microwaves emitted in a microwave oven. The results of such simulations are useful for practical applications to improve the quality of foodstuffs and increase the diversification of domestic foodstuff as an effort to strengthen the nation's food security [8]. This research will study the heat distribution of a local food ingredient, namely sweet potato, both spatially and temporally by varying the geometri shape and size of sweet potatoes.

RESEARCH METHODS

The tool used in this study uses a laptop with Comsol Multiphysics 5.5 software (trial version) [9]. Comsol Multiphysics software is a tool used to simulate the temperature field distribution in sweet potatoes. Microwave ovens that are used as physical models in the construction of heat distribution equations are generally microwave ovens with an output of 200 W and a frequency of 2.45 GHz.

The steps of this research consist of:

a. Establishment the Physical Model. Physical construction is made by considering the length of the Microwave Oven type that will be used in this study. Microwave Oven physical construction is built using Comsol Multiphysics 5.5

b. Input the physical parameters of sweet potatoes and the power of microwave oven. Physical parameters become the boundary conditions that will be used in the process to simulate the heat distribution with the parameters are shown in Table 1.

TABLE 1. Physical Properties of Sweet Potatoes

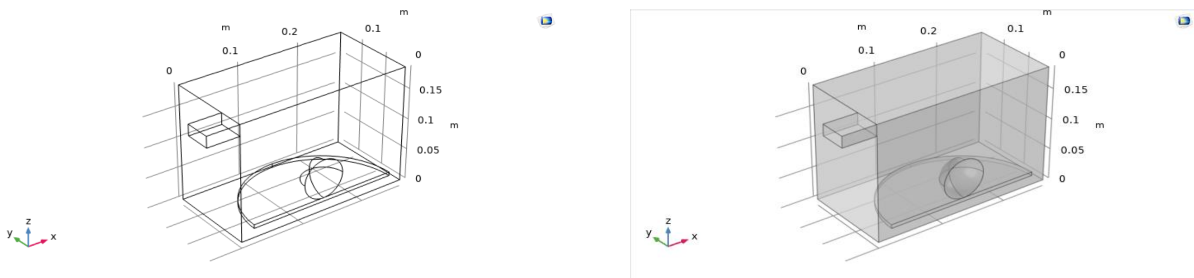
Symbol	Value	Unit	Description
ε'	69.7	1	Dielectric Constant
ε''	14.5	1	Dielectric Loss Coefficient
μ	1	1	Magnetic Permeability
σ	0	S/m	Conductivity
k	0.49	W/(m.K)	Thermal Conductivity
ρ	577	Kg/m^3	Density
C_p	3660	J/(kg.K)	Specific Heat Capacity

c. Analyze the result. The simulation results using Comsol on sweet potatoes will be analyzed to determine how the heat distribution occurs in sweet potatoes and how long it takes the temperature of the sweet potatoes to be spread in sphere and cylindrical shape.

RESULTS AND DISCUSSION

Physical Model

Figure 1 shows the physical construction of a half-part model of the microwave oven, this is so that the heat distribution that occurs at the centre point of the sample can be observed in the heat distribution process that occurs in the sample. The full model is shown in Fig. 2 with the physical model components consisting of a microwave oven cavity, a waveguide, a glass tray, and a sweet potato sample following the general microwave oven model. The size of the cavity was length wo = 0.267 m, width do = 0.27 m, and height ho = 0.188 m, and the waveguide was length wg = 0.05 m, width dg = 0.078 m, and height hg = 0.018 m.



a. b.

FIGURE 1. Physical Model (Half model)

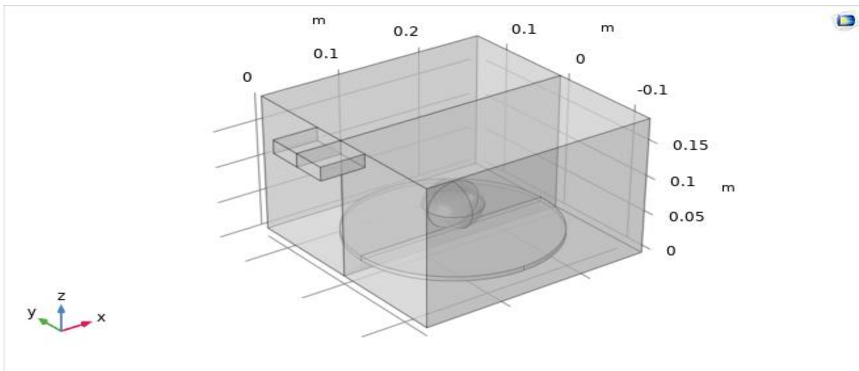


FIGURE 2. Physical Model (Full Model)

Heat Distribution in Sweet Potatoes with Different Shape

The distribution of heat generated in the sweet potato sample caused by the propagation of electromagnetic waves is shown in Fig. 3 and Fig. 4 below. Conventional heating is different from heating food using microwaves. The increase in temperature caused by microwave propagation does not occur from the surface of the sample, but occurs from the center of the sample that propagates to the surface. This is in accordance with research from [7] which shows the distribution of heat on spherical objects starting from the center of the sample. Figure 3 shows the distribution of heat that occurs in a ball with a radius of 31.5 mm with a temperature in the center of the ball reaching 100^{o}C in 15 seconds, then heat begins to propagate towards the surface of the ball. According to [10], this indicates that the rate of heat collection that occurs during the microwave heating process is faster than the rate of heat conduction. Heat distribution using microwaves starting from the center of the sample also applies to the cylindrical shape as shown in Fig. 4. The time required for the temperature to reach 100^{o}C is slightly longer, which is 20 seconds and the distribution is more evenly distributed than the sphere. Hot spots that start to appear at 5 seconds and increase the temperature to 100^{o}C longer than the ball. The shape of the cylindrical surface causes an increase in temperature at the center of the sample. The ball experiences a faster temperature increase compared to the cylinder because half of the thickness of the cylindrical object, which is 21 mm, is smaller than the value of the penetration depth of sweet potato as 28.9 mm, so the rotating dipole only comes from the direction around the cylindrical blanket, in contrast to the ball where the dipole rotates from in all directions because of the symmetrical shape of the ball.

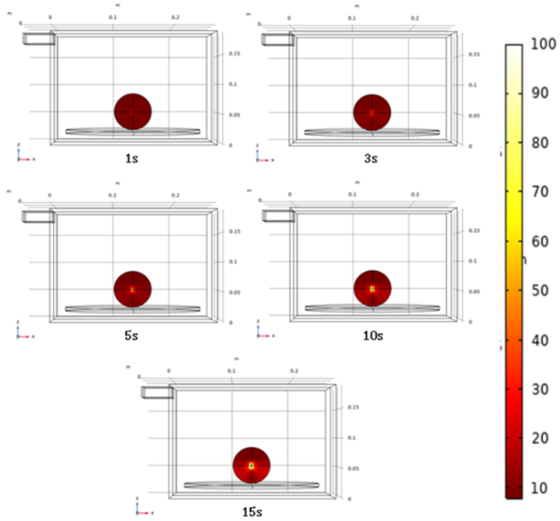


FIGURE 3. Heat distribution in a ball with a radius of 31.5 mm

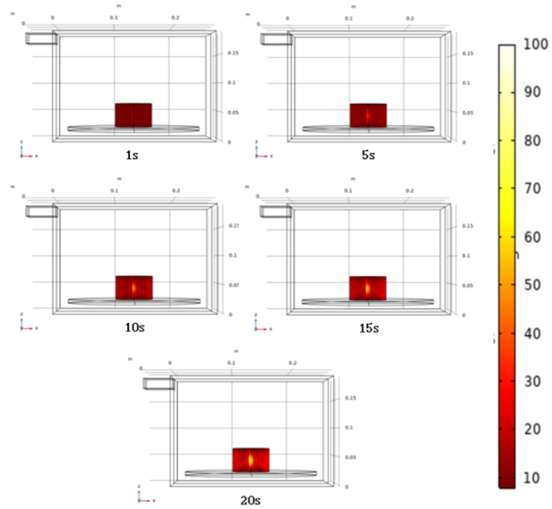


FIGURE 4. Heat distribution in a cylinder with a radius of 31.5 mm and a height of 42 mm

Heat Distribution Due to Size Difference

The size difference in the sweet potato samples heated using microwaves also affects the heat propagation process that occurs in the sample as showed Fig. 5 and Fig. 6. The thickness of the sample affects the distribution of heat that occurs in the sample, because the depth of penetration is an equation that depends on the thickness of the sample. The comparison of the heat distribution that occurs in spherical objects with radii of 31.5 mm and 42 mm can be seen in Fig. 5 above. Figure 5 shows the distribution of heat in spheres of different sizes. On a sphere with a radius of 42 mm, it can be seen that the distribution of heat that occurs in the sample is uneven and it takes 60 seconds for some parts of the sample to reach a temperature of around 80ºC. However, the heat generated is almost complete throughout the sample. A spherical sample with a larger size takes a long time because the amount of material contained in the sample affects the amount of energy and the length of time it takes to enter the sample. Seen at 60 seconds, the temperature in the large ball sample reaches 80ºC and the temperature is in the middle and to the left of the sample. The heat that occurs on the left of the sample is caused because the energy that is distributed is greatest on the right of the sample, so the energy penetrates directly from the sample from the right and the energy is converted into heat and propagated from the right to the left, so that the heat starts from the center of the sample to the left sample.

In a cylindrical object, the heat generated is different from that of a spherical object. A comparison of the heat distribution that occurs in cylinders of different sizes is shown in Fig. 6. The increase in temperature that occurs in a large cylindrical object is the same as a sphere, it takes 60 seconds for the temperature to reach the range of 80ºC. The volume of the cylindrical object is set as large as that of the large spherical object in order to analyze the difference in heat distribution without looking at the amount of material in the sample. In the cylindrical object, the heat generated in the sample is different from the other shapes and sizes that have been discussed, the heat generated in the cylindrical object is not in the center of the sample but is at the left end of the sample and the heat has increased significantly at 60 seconds compared to with other areas where the temperature only reaches in the range of 40-50ºC.

The depth of penetration is very influential on changes in the size of the sample heated using microwaves. It can be seen that the sample with a thickness of 42 mm radius maximum temperature occurs at the tip of the sample, applies to spherical objects and cylindrical objects. This is not only due to the uneven distribution of the electric field on the inside of the oven, another cause is also influenced by the thickness of the sweet potato sample which has far exceeded the penetration depth of the sweet potato so that the absorption of electromagnetic wave energy is greatest at the tip of the sample. which causes the dipoles at the tip of the sample to rotate the fastest and the resulting temperature is also high.

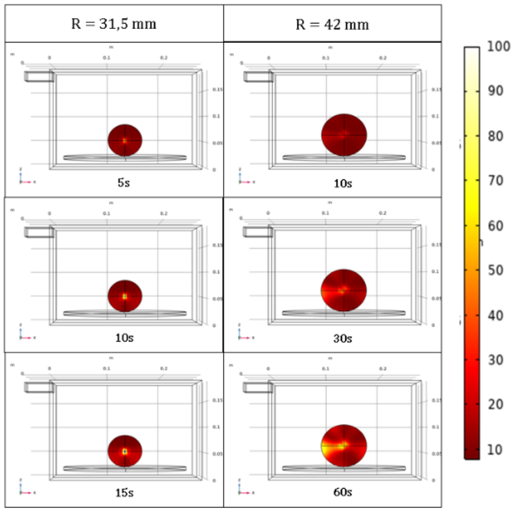


FIGURE 5 Comparison of heat distribution on the ball due to the difference in size

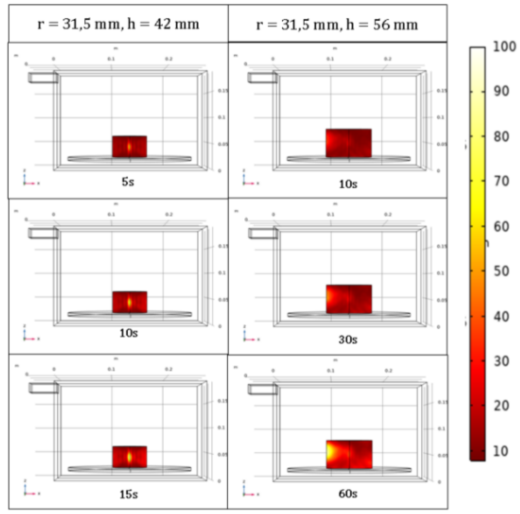


FIGURE 6 Comparison of heat distribution in cylinders due to size differences

CONCLUSION

The shape and size of the sweet potato affect the heat distribution in the sweet potato material. The spherical shape has a faster heat distribution than the cylindrical shape. The ball with a radius of 42 mm has an even distribution of heat with a temperature increase that occurs throughout the sample so that it has a fairly good level of maturity. Cylindrical shape with a radius of 42 mm and a height of 56 mm has an uneven distribution of heat.

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