DETERMINATION OF THERMAL CONDUCTIVITY OF AMBON BANANA (*Musa paradisiaca L.*) IN ONE DIMENSIONAL HEAT TRANSFER MECHANISM

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Abstract

The knowledge of thermal conductivity (k) is very important to estimate the flux of heat transfer on material. The thermal conductivity Ambon Banana fruit (Musa paradiciaca L.) has been exploited in our works and the results are important for constructing a system of food manufacture process such as heating, cooling, drying etc.

The aims of this experiment are; 1) to determine the thermal conductivity of Ambon banana fruit, 2) to know an influence of temperature gradient on the thermal conductivity.

The configuration of experiment are fixed and they are; 1) the heat transfer in one dimensional, 2) the initial and boundary condition in certain value, 3) material considered homogeny, and 4) experiment in unsteady state condition

The thermal conductivity is calculated by the numerical method (Method of Crank Nicholson). The Ambon banana fruit is milled to obtain the homogenize of size and physical characteristic material. The given temperature treatment is of 40°C and of 70°C.

We obtain that the mean of thermal conductivity of Ambon banana fruit at temperature of 40°C is (0.525±0.031) W/m°C and of 70°C is (0.530±0.066) W/m°C. We can make a conclusion that the higher of gradient temperature, affect thermal diffusivity.

Keywords : thermal conductivity, heat transfer, unsteady state, one dimensional.

Nomenclature

C_p	: Specific heat	(kJ/kg^{o}C)
k	: Thermal Conductivity	(kJ/m.hour)
l	: length of cylinder	(m)
mb	: total mass of matter	(kg)
r	: radius of cylinder	(m)
t	: time	(min)
v	: Volume of cylinder	(m^3)
w	: water content	(%)
x	: distance	(m)
α	: Thermal diffusivity	(m^2/hour)
ρ	: Mass density	(kg/m^3)

INTRODUCTION

Thermal properties of material are very important to be known for designing of

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foods processing as like: drying, heating, cooling, evaporation etc. They are influenced by material composition. The thermal properties of matter are thermal conductivity (k), specific thermal Cp) and thermal diffusivity (α).

The knowledge of thermal conductivity is very important for predicting the heat flux of conduction in the matter (unklesbay et al, 1992 in Goedeken, Shah and Tory, 1998). The value of k obtained is available to design the processing system as heating, refrigerating and drying process. According the conduction equation, the quantity of heat transmission in the matter depends on the value of k. Thermal conductivity of matter can be determined by solving numerically the Fourier equation. The thermal conductivity is calculated in unsteady state condition. In our work, this method was exploited and the Ambon banana fruit (*Musaparadisiaca L*) was used as research material.

The goals of this research are a) to determine the thermal conductivity of ambon banana, b) to know the influence of temperature on the thermal conductivity. The research conducted provides the value of k that can be use as reference value in designing of food processing.

According to Sweat, 1974 (in Mohsenin, 1980), the thermal conductivity of banana with moisture content of 75.7 % is 0.481 W/m^{o}C at the temperature of 27 ^{o}C and density of 980 kg/m^3. Heat transfer by conduction is one heat transfer mechanism that occurs in the heating process. In Conduction, heat can be conduced through solid, liquid and gases. The heat is conducted by the transfer of energy of motion between adjacent molecules. Conduction heat transfer is divided to two condition: the first condition is occurred in steady state where temperature doesn't change proportional to time in the fix location and the second condition is the heat transfer in unsteady state. Unsteady state is occurred if the temperature change proportional to time on the fix certain location. Temperature gradient that exists in the homogeneous matter will cause the conduction heat transfer.

As long as unsteady state conduction heat transfer, the change of temperature occurs in the function of time and spatial. In steady state conduction, the temperature is change about the distance (Heldman and Singh, 1981). Thermal conductivity is assumed in constant about time, temperature and composition. It is also determined by the equation (1)

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The equation (1) is the Fourier equation applied for heating and refrigerating problems with geometry approach for infinite slab and heat transfer in x direction (Berverloo & Leniger, 1975)

RESEARCH METHOD

The research was conducted at Agricultural Processing Laboratory, Faculty of Agricultural Technology, University of Brawijaya Malang. The material used is the Ambon Banana that has optimal overripe. The equipments consist of blender, thermometer, balancing, knife and thermal conductivity meter. The thermal conductivity meter is formed of the several components as: heater, thermocouple, thermocontrole, container of material and a fluid as heat transfer medium.

Numerical method can be used to solve the equation (1) in the frame to obtain the value of α. The equation (1) is discretized by using the implicit method of Crank – Nicolson (Sastry – 1979). The implicit method has superiority in which the stability in calculating of α is guaranteed.

The derivative equation of temperature to time and distance can be approached with:

$$\frac{\partial T}{\partial t} = \frac{T_{(i,j+1)} - T_{(i,j)}}{\Delta t}$$

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{2}\left[\left(\frac{T_{(i-1,j)} - 2T_{(i,j)} + T_{(i+1,j)}}{\Delta x^2}\right) + \left(\frac{T_{(i-1,j+1)} - 2T_{(i,j+1)} + T_{(i+1,j+1)}}{\Delta x^2}\right)\right]$$

$$\frac{\partial T_{(i,j+1)}}{\partial t} = \alpha \frac{\partial^2 T_{(i,j+1))}}{\partial x^2} \quad \ldots\ldots\ldots\ldots(2)$$

where :
$x = i$, $i = 1, 2, 3, \ldots, m$, $m = 7$
$t = j$, $j = 0, 1, 2, \ldots, n$, $n = 10$

From the equation (2) obtained :

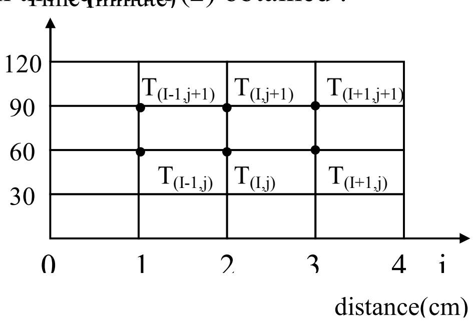


Figure 1. Schematic diagram of calculation of α based of value of T (x, t)

$$\alpha = 2\frac{\Delta x^2}{\Delta t}\left[\frac{T_{(i,j+1)} - T_{(i,j)}}{T_{(i-1,j)} - 2T_{(i,j)} + T_{(i+1,j)} + T_{(i-1,j+1)} - 2T_{(i,j+1)} + T_{(i+1,j+1)}}\right]$$

……………………….(3)

With :
$T(x, 0) = T_o$ (initial condition)
$T(0, t) = T_1$ (left boundary condition)
$T(L, t) = T_2$ (Right boundary condition)
Δt = step of time
Δx = step of distance

Apparent Density (ρ) is the ratio between mass of matter with its volume. The value of ρ is determined as follow:

$$\rho = mb/v \quad \ldots\ldots\ldots\ldots\ldots\ (4)$$

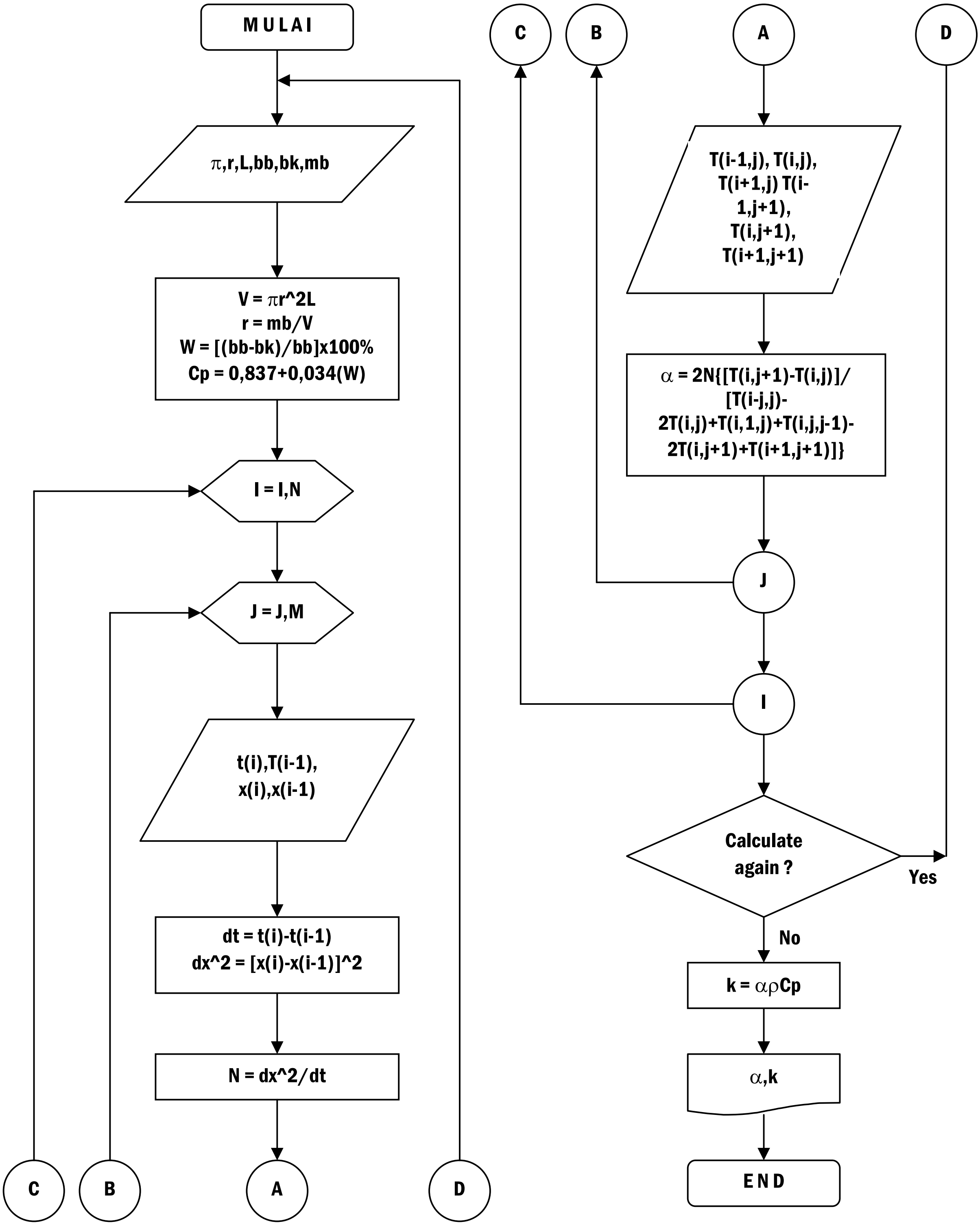


Figure 2. Flow Chart of the Research Conducted

The specific heat (C_p) is the amount of heat that accompanies a unit change in temperature for a unit mass (Toledo, 1984). The value of specific heat of fruits with moisture content above of 50 %, is written by Siebel (1982) as follow :

$C_p = 0.837 + 0.034\ W$ ……………… (5)

Thermal diffusivity (α) is a ratio between thermal conductivity and volumetric heat capacity (Henderson & Perry, 1976) and is formulated as :

$\alpha = k/(C_p\rho)$ ……………… (6)

Thermal diffusivity (α) is derivative characteristic that represent the time of heating and deal with heat transfer in unsteady state (Mohsenin, 1980). Thermal conductivity can be explained with equation as:

$k = \alpha\ \rho\ C_p$ ………………… (7)

RESULT AND DISCUSSION

Determining of k value needs data of physic and thermo like as specific mass (ρ), thermal diffusivity (α), and specific heat (C_p). The value of k is linier proportional to α, C_p and ρ. Thermal conductivity of ambon banana can determine after thermal diffusivity value determined (equation 7). The result of k value for different moisture content and density showed in Table 1.

1. Bulk Density

Table 1 shows that the highest bulk density value is 966.969 kg/m^3 to moisture content of 76.13 %, and the lowest bulk density value is 943.269 kg/m^3 to moisture content of 77.40 %. Bulk density value decrease since the moisture content of material increase.

Table 1.
Thermal Conductivity of Ambon Banana

Heating treatment	Moisture content (%)	ρ (kg/m^3)	Cp (kJ/kg ^{o}C)	α_{avg} (m^2/s)	K (W/m ^{o}C)
40 – 40 ^{o}C	77.16	950.378	3.460	1.5 x 10^{-7}	0.493
	77.23	948.009	3.463	1.6 x 10^{-7}	0.525
	77.40	943.269	3.469	1.7 x 10^{-7}	0.556
Average	77.27	947.219	3.464	1.6 x 10^{-7}	0.525
70 – 40 ^{o}C	76.13	966.969	3.425	1.4 x 10^{-7}	0.464
	76.73	962.229	3.446	1.6 x 10^{-7}	0.531
	76.80	959.859	3.448	1.8 x 10^{-7}	0.596
Average	76.55	963.368	3.44	1.6 x 10^{-7}	0.530

2. Specific Heat

Table 1 shows that the highest specific heat value for 40 ^oC heating treatment is 3.469 kJ/kg ^oC to moisture content of 77.40 % and the lowest specific heat value is 3.460 kJ/kg ^oC to moisture content to 77.16 %. The highest Cp value for 70 ^oC heating treatment is 3.448 kJ/kg ^oC to moisture content of 76.80 % and the lowest Cp value is 3.425 kJ/kg ^oC to moisture content of 76.13 %.

Since moisture content increase, the value of specific heat of Ambon banana will increase. Since the moisture content high, percentage of water higher than solid. The highest of the average value of specific heat for 40 ^oC heating treatment is 3.464 kJ/kg ^oC, and the lowest of the average value of specific heat is 3.440 kJ/kg ^oC. At the temperature range of 40 – 70 ^oC, the different value of specific heat not significant.

The high temperature will reduce specific heat of banana. Gelatinization process will occur at the temperature of 70 ^oC, which particle of free water bounded by particle of Carbohydrate. The more quantity of bounded water in the material will reduce value of C_p.

3. Thermal diffusivity

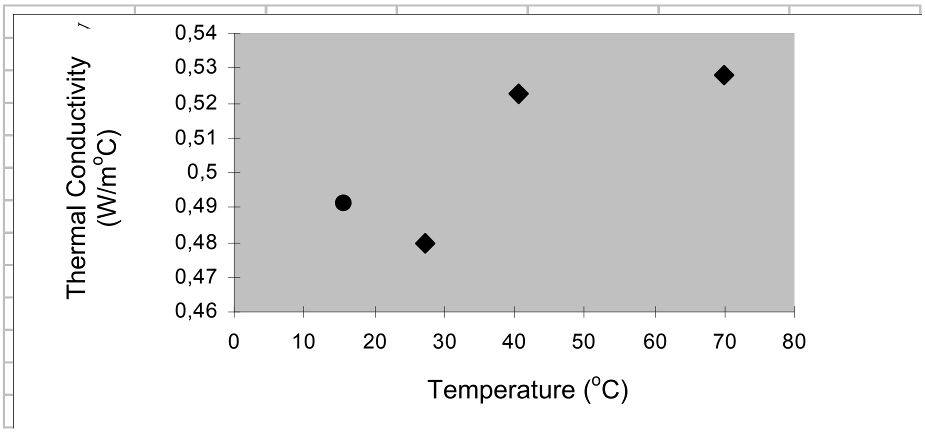
In Table 1 can be observed that the value of thermal diffusivity (α) will be more and more large with the more large of water content, either in the heating treatment of 40^oC or of 70^oC. It can be explained that the value of α depends the values of Cp and of k. The value of k and Cp is in linier proportion with the water content, with the result the values of Cp and k will be more and more large with the more of water content.

The value of thermal diffusivity (α) depends on the data of temperature obtained in the experiment. The fluctuate temperatures in the material over the experiment give the values of thermal diffusivity in same tendency. The value of α in sign minus indicate that the direction of heat transfer in countercurrent with actually. This condition can be caused by the existing of pores in the material of banana and so that the heat transfer is accompanied with the mass transfer. Finally, the distribution of temperatures in the material are also little deviate.

4. Thermal Conductivity.

The average of thermal conductivity of Ambon Banana at heating temperature of 40°C is of 0,525 W/m°C and at the heating temperature of 70°C is of 0,530 W/m°C. Whereas the thermal conductivity of banana porridge according the reference is of 0,481 W/m°C at temperature of 27°C (Mohsenin, 1980).

The highest value of thermal conductivity is occurred for the highest values of moisture content for every treatment. It caused by the k and C_p value which proportional to moisture content, and the value of k depend on thermal diffusivity (α) and on specific heat (C_p). More and more high the value of specific heat and the value of thermal diffusivity then the value of thermal conductivity is higher and higher. The same tendency between the value of moisture content (w) and the value of thermal conductivity (k) is occurred for red apple (Bennet *et al*.,1969) and bean (Sutter *et al*., 1972) in Mohsenin (1980).



Explanation :
- References
- Research

Figure 3. Correlation between heating temperature (°C) and thermal conductivity (W/m°C) for Ambon Banana.

Figure 3 shows that the higher temperature treatment gives the increasing of thermal conductivity. According to Thomson, 1918 in Goldblith et al., 1961, the higher temperature cause the inclination of thermal diffusivity for some matter, and thermal conductivity will tend to increase too if it receive the higher temperature.

CONCLUSION

1. The thermal conductivity average of Ambon banana at heating temperature of 40°C and of 70°C are of (0,525±0,031) W/m°C and of (0,530±0,066) W/m°C respectively.
2. On the range of 40°C to 70°C, the thermal conductivity of Ambon banana is more higher

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