Technical Paper

THERMAL DIFFUSIVITY OF SWEET POTATO FLOUR MEASURED USING DICKERSON METHOD

Difusivitas Panas Tepung Ubijalar Diukur Dengan Metode Dickerson

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Abstract

Sweet potato (Ipomoea batatas l.) is one of the carbohydrate sources in Indonesia that can be used both for food and industry purposes. To support the utilization of sweet potato as flour, it is imperative to develop a drying system that can improve its quality. A preliminary study using an improved variety, namely Sari, was conducted to determine its flour thermal diffusivity (α), an important parameter in developing drying process. The experiment was run according to Dickerson method using sweet potato flour at different levels of moisture content (5.05 – 5.97 % wet basis) and temperatures (23.7 – 40.9 °C). This method used an apparatus based on transient heat transfer condition requiring only a time-temperature data. At the levels of moisture and temperature studied, the thermal diffusivity of sweet potato flour could be expressed using a linear regression model, $\alpha = 10^{-9} M \cdot T + 9x10^{-8}$ ($R^2 = 0.9779$). The average value of the thermal diffusivity sweet potato flour was $1.72x10^{-7}$ m^2/s at a moisture level of 5.51 % wet basis and temperature of 29.58 °C. Similar studies are needed for different varieties or cultivars of sweet potato as well as at a wide range of moisture content and temperature levels.

Keywords: *Sweet potato flour, thermal diffusivity, Dickerson Method.*

INTRODUCTION

Sweetpotato (*Ipomoca batatas l.*) is a carbohydrate source that can be utilized for food as well as a raw material in industry in Indonesia. It has a big potential to substitute some of wheat imported in Indonesia which is around 3 million ton annually. From one hectar harvested areas it can be produced about 7.50 tons of sweetpotato flour. If the total area of sweetpotato in Indonesia is 225,000 hectares, 1.70 billion tons of sweetpotato flour could be produce per year. Utilization of sweetpotato flour for food industries could reduce the import of wheat flour about 1.40 million tons valued at US $ 302 million per year (Heriyanto, et. al., 2001).

In relation with food diversification program, processed sweetpotato flour has higher value-added (Rp 3,000 /kg) compared to roots (Rp 500 /kg) (Heriyanto, et. al., 2001). However, the quality of sweetpotato flour sold at local market is low due to the lack of drying

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and there are no information on its moisture content and expiry date. Therefore, it is necessary to improve sweetpotato flour through enhancement on drying system as well as on milling and packaging systems.

One physical parameter that is important in developing sweetpotato flour drying process is its thermal diffusivity value. Thermal diffusivity is defined as the ability of a material to conduct thermal energy relative to its ability to store thermal energy. It helps estimate processing time of canning, drying, heating, cooling freezing, cooking or frying. It determines how fast heat propagates or diffuses through a material. It is affected by water content and temperature as well as composition and porosity (Anon., 2002).

Hassan and Hobani (2001) stated that values of thermal diffusivity of food materials is required to predict heat transfer rates during thermal operation such as drying, heating, cooling and freezing. It is necessary to ensure the quality of the food product and the efficiency of the equipment. Thermal diffusivity of Sweetpotato flour can be measured either directly through recognized experimental procedure or indirectly using the following formula (Mohsenin, 1980):

$$\alpha = k / (\rho C_p) \qquad (1)$$

where α is thermal diffusivity (m^2/s), k is thermal conductivity (W/m K), ρ is density (kg/m^3) and C_p is the specific heat (J/kg K).

The indirect approach is not favored because it requires considerable time and complicated instrumentation for measuring the values of k, ρ, and Cp (Singh, 1982). Meanwhile, reliable value of k is limited in the literature and sometime its difficult to determine experimentally (Gaffney et al., 1980). The accuracy of thermal diffusivity values is therefore dependent on the accuracy of this property.

Bambang et al. (2000) measured thermal diffusivity of Ambon banana fruit directly using numerical method developed by Crank Nicholson (Sastry, 1979). However this method needs more than three sensors for temperature measurement. Therefore its accuracy dependent on the accuracy of the temperature measured.

Considering the weakness of measurement of thermal diffusivity using indirect method and numerical methods, this study was conducted to determine thermal diffusivity of sweetpotato flour using the transient methods of Dickerson (1965). Dickerson method used transient heat transfer conditions requiring only a time-temperature data.This method was used by Hassan and Hobani (2001) to determine thermal diffusivity of date paste. Tastra (2004) also used the Dickerson method for measuring arrowroot flour thermal diffusivity.

MATERIALS AND METHOD

Sweetpotato flour of Sari Variety was used in this study. An oven dry method was used to measure the moisture content of the sweetpotato flour (AOAC, 1970).

The experiment was setup (Figure 1) according to the Dickerson method consisted of a metal cylinder with an internal diameter (d) of 0.082 m, external diameter (D) of 0.088 m and a height (L) of 0.40 m, with two wooden caps for the two open ends of each cylinder. Data Logger Type RDL – 15C (Anon, 1995) was used to measure the cylinder surface and sample center temperatures. To attain a constant heating rate, 600 W electrical heater was used. A cylinder water-heating bath with an internal diameter of 0.15 m and a height of 0.43 m was used. According to Dickerson (1965), the heat transfer equation expressing temperature as a function of radial distance (r) from the heat source can be written as:

$$\frac{A}{\alpha} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} \qquad (2)$$

Where A equals the constant rate of temperature rise at all points in the cylinder, °C/s; T is temperature, °C, r is radial distance from heat source, m. Since temperature gradient is no longer time (θ) dependent in Eq. (2), ∂^2 can be changed to d^2 with the following solution:

Letting surface and center temperatures be Ts, and Tc for the boundary condition of

$$T + A = Ts \qquad \theta > 0, r = D/2$$
$$\qquad \theta > 0, r = r$$

$$\frac{dT}{dr} = 0, \qquad \theta > 0, r = r$$

The solution reduces to

$$(Ts - T) = \frac{A}{4\alpha}((D/2)^2 - r^2)$$

Taking r = 0

$$\alpha = \frac{A D^2}{16(Ts - Tc)} \qquad 3$$

where Ts and Tc are the outside surface of cylinder and sample center temperatures, respectively. D is the external diameter of the cylinder (Figure 1).

The cylinder with bottom wooden cap was filled with the sample under test. The top wooden cap was carefully placed with temperature sensor towards the center of the sample inside the cylinder. Surface a nd center temperature sensors were connected to the data logger.

The experiment was stopped when the sample center temperature reached about 80 °C to make sure that the rate of temperature rise of surface and the center of the sample inside the cylinder is equal. The sample was then taken out for moisture content determination. This procedure was replicated four times to randomly determine at different temperatures (T) and moisture contents (M).

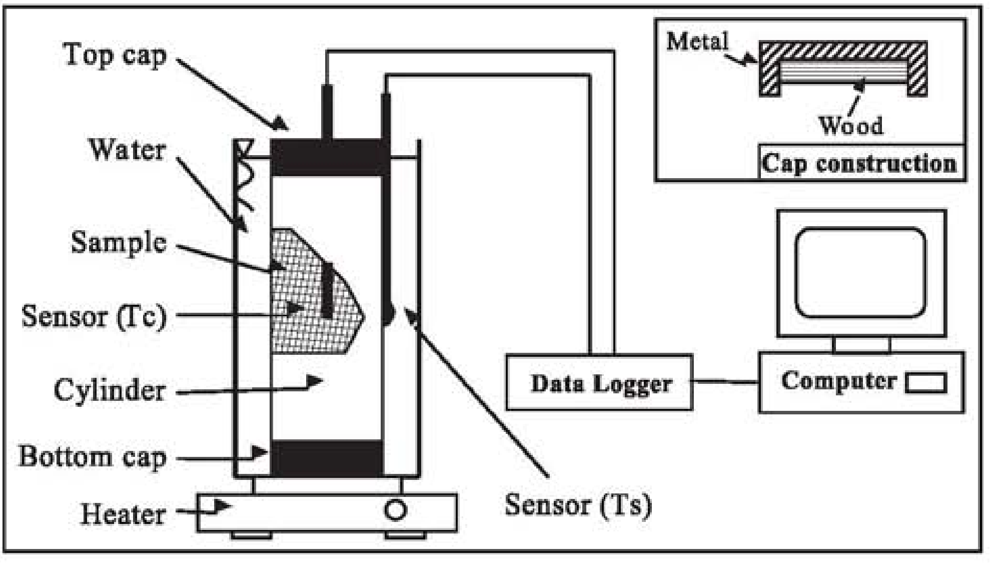
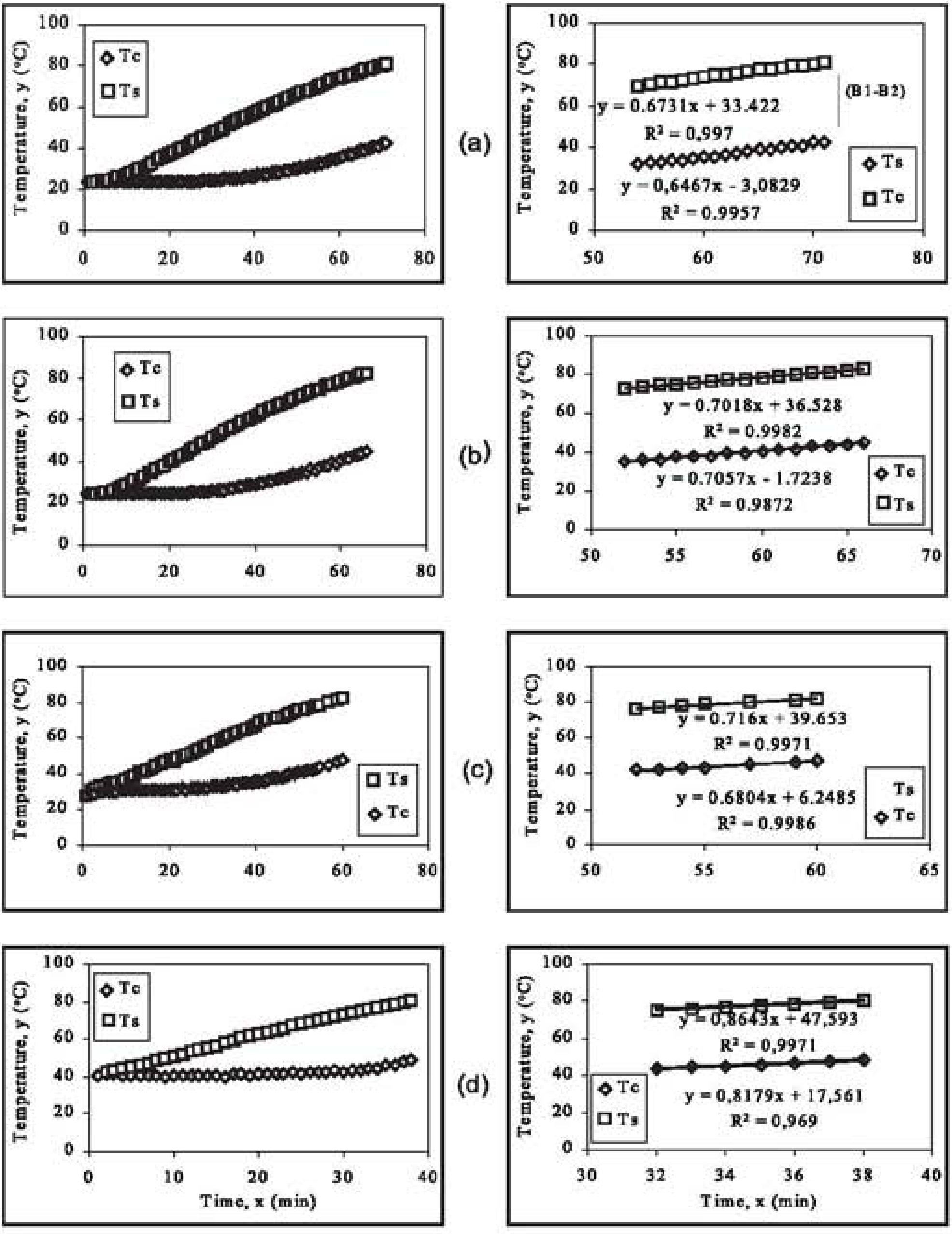


Fig. 1: Apparatus for direct measurement of thermal diffusivity of sweetpotato flour (Dickerson, 1965; Tastra, 2004).



(P) (Q)

Fig. 2. (P) Measurement of the cylinder surface (Ts) and sample center (Tc) temperatures at different levels of moisture content (M) and temperature (T) of Sweetpotato flour (a) M = 5.97 % w.b., T = 23.7 °C; (b) M = 5.46 % w.b., T = 24.5 °C; (c) M = 5.56 % w.b., T = 29.2 °C; (d) M = 5.05 % w.b., T = 40.9 °C and (Q) the linear regression analysis of the straight-line portion of the cylinder surface and sample center temperature curves after the transient portion was eliminated that is used to determine the value of (B1-B2), Eq. (4).

Table 1: Sweetpotato thermal diffusivity () at different moisture contents (M) and initial sample center temperatures (T), calculated based on data in Figure 2.

Treatment	M (% (w. b.))	T (°C)	B1-B2 [1] (°C)	A [2] (°C / s)	α [3] (m^2 / s)	Average (R^2) [4]
a	5.97	23.7	36.505	0.6599	1.46×10^{-7}	0.996
b	5.46	24.5	38.252	0.7038	1.48×10^{-7}	0.993
c	5.56	29.2	33.405	0.6962	1.69×10^{-7}	0.998
d	5.05	40.9	30.032	0.8411	2.26×10^{-7}	0.983
Average	5.51	29.6			1.72×10^{-7}	0.992

1) Intercept differences (Eq. 4) of linear regression of surface (Ts) and sample center (Tc) temperature.
2) Average linear regression coefficient of surface (Ts) and sample center (Tc) temperature multiplied by conversion factor (1/60) to convert unit °C / min to °C/s.
3) Calculated based on Eq. (3) at external cylinder diameter (D) 0.088 m.
4) Average coefficient determination (R^2) of regression of surface and sample centre temperature, Eq.(4).

Table 2. Summary of the homogeneity test of regression coefficients in Figure 2 (Q) (Gomez and Gomez, 1984).

Treat-ment	Moisture content , M (% w. b.)	Tempe-rature, T (°C)	Regression Coefficient		t-Table (5%)		t-Calcu-lated	Remark
			A1 [1]	A2 [1]	d.f. [3]	value		
a	5.97	23.7	0.6731	0.6467	32	2.04	-1.86	n.s [2]
b	5.46	24.5	0.7018	0.7057	26	2.04	0,17	n.s
c	5.56	29.2	0.7160	0.6804	10	2.23	-1.72	n.s
d	5.05	40.9	0.8643	0.8179	10	2.23	-0.68	n.s

1) Eq. (4), the values of coefficient regression are taken from Fig. 2 (Q).
2) not significant (n.s.)
3) degree of freedom (d.f.) = (2 x n - 4), where n is the number of data used in regression analysis (Figure 2 (Q)).

To minimize error in determining the value of A and (Ts – Tc), which will determine the value of α (Eq. 3), linear regression analysis using EXCEL program was used in determining the same heating rate of the surface and the center of the cylinder. Suppose Ts and Tc can be expressed as:

$$Ts = B1 - A1 \cdot X$$

$$\text{and } Tc = B2 - A2 \cdot X \qquad (4)$$

After determination of α at different levels of T and M, the following equation could be derived :

$$\alpha = a\, M \cdot T + b \qquad (5)$$

where a and b are constant. This simple descriptive model was derived based on hypothesis that is α dependent on the product of temperature (Bambang et al., 2000) and moisture content (Riedel, 1969).

RESULTS AND DISCUSSION

Experimental values of Sweetpotato flour Thermal diffusivity

Experimental time-temperature data of sweetpotato flour at different level of moisture content and initial sample center temperature are illustrated in Figure 2 (P). While Figure 2 (Q) showed the results of linier regression analysis of the elevated temperature both in and outside the cylinder as seen in Figure 1. The rate of heating (A) was taken from the straight-line portion of the cylinder surface and sample center temperature curves after the transient portion was eliminated. This was done based on the Eq. (4). After that thermal diffusivity (α) was determined using Eq. (3) as presented in Table 1. For example, using data on treatment (c) in Figure 2, A = (0.716 + 0.6804)/(2x60) (°C/s), (B1-B2) = (39.653 - 6.2485) (° C) and then the calculated = 1.69 x 10^{-7} (m^2/s).

The average value of α was 1.72 x 10^{-7} m^2/s, at a moisture content 5.51 % (w.b.) and sampler temperature 29.6 °C with coefficient determination (R^2) > 0.95 (Table 1). In addition, the homogeneity test of both regression coefficients (A1, A2, Eq. (4)) in each treatment (Table 2) showed that the two regression coefficients are homogeneous due to t-Calculated < t-Table (5%). In conclusion, A1 is statistically equal to A2. Therefore, A in Eq.(3) is equal to (A1 + A2)/2. Showing that the method was still reliable. The method is also more practice as it did not use a teflon as an insulator and did not need a stirrer (Dickerson, 1965).

The effect of Moisture content and Temperature on sweetpotato flour Thermal diffusivity

In the range of moisture content (M) 5.05 – 5.97% w.b. and temperature (T) 23.7 – 40.9 °C (Table 1), thermal diffusivity of sweetpotato flour can be expressed as $\alpha = 10^{-9}$ M·T + 9x10^{-9} with coefficient determination R^2 = 0.9779 (Figure 3). This suggests that the diffusivity value of sweetpotato flour can be estimated from the values of moisture content and temperature. Martens (1980) *in* Hassan and Hobani (2001) also reported the high moisture content (X_w) and temperature (T) contribution in calculating the diffusivity value of a variety of food products, eventhough the equation is slighty different, as α = [0.057363 X_w + 0.000288 (T+273)] X_w probably due to differences in material form, range of temperature and moisture content.

In addition Tastra (2004) found the same model used in this study can be used for estimating the diffusivity values of arrowroot flour. However, the homogeneity test of both regression coefficients showed that the trend was different (Figure 4). This may due to differences in moisture content and chemical composition. These two studies suggests that the model can be applied as well to estimate the diffusivity value of other flours particularly derived from root crops.

CONCLUSIONS

1. Based on this study sweetpotato flour diffusivity can be expressed as α = 10^{-9} M·T + 9x10^{-9} (R^2 = 0.9779) for the of moisture content range of 5.05 – 5.97 % (w.b.) and temperature range of 23.7 – 40.9 °C.
2. The average value of sweetpotato flour diffusivity was found to be 1.72x10^{-7} m^2/s, at moisture content of 5.51 % (w.b.) and temperature of 29.58 °C.

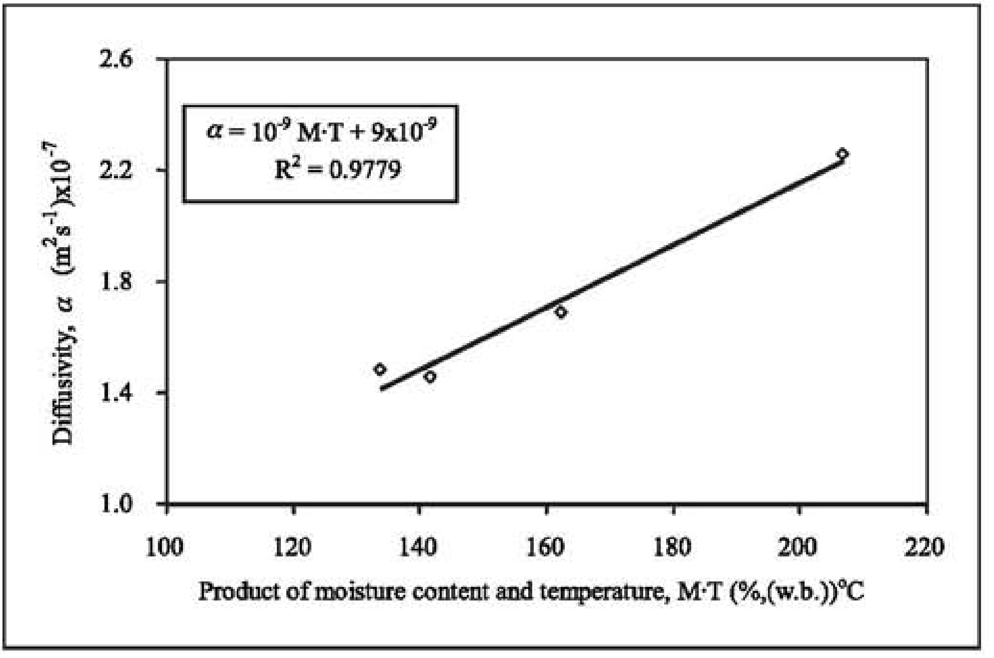


Fig. 3. Diffusivity of sweet potato flour as a function of moisture content (M) and temperature (T).

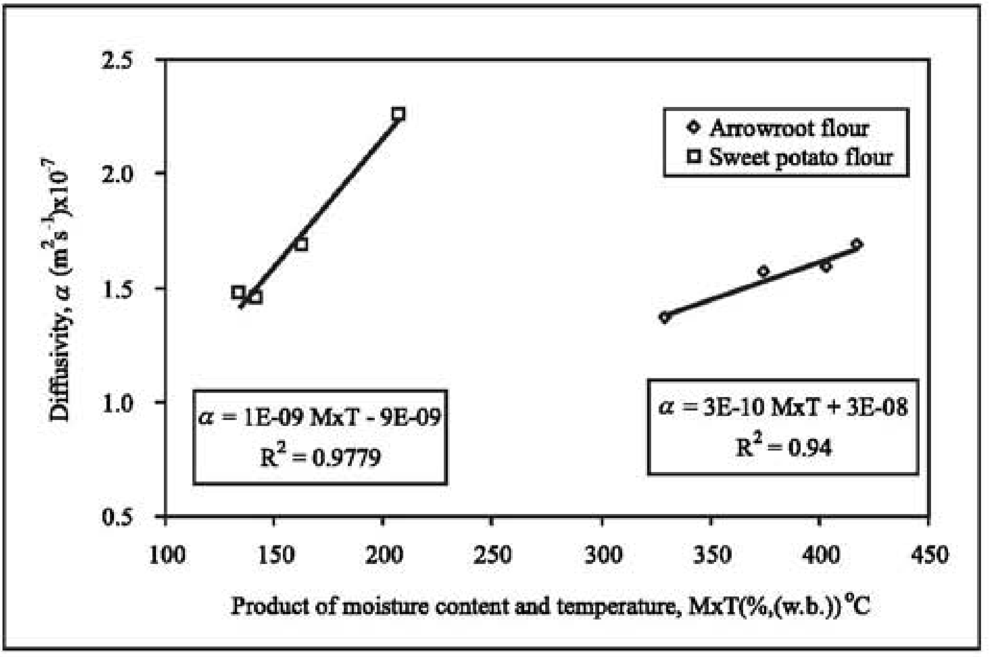


Fig. 4. Homogeneity test the coefficient regression of the diffusivity of sweet potato and and arrowroot flour as a function of temperature (T) and moisture content (M) (t-Calculated : 6.17 > t-Table (0,05; 4) : 2.78).

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