

## **MEASUREMENT OF THE THERMAL DIFFUSIVITY OF SWEET POTATO FLOUR USING DICKERSON METHODS**

I.K. Tastra, Erliana Ginting dan Ratnaningsih

Balai Penelitian Kacang-kacangan dan Umbi-umbian

### **ABSTRAK**

Ubijalar merupakan salah satu sumber karbohidrat yang dapat diolah untuk tujuan pangan dan industri. Untuk mendukung diversifikasi pengolahan ubijalar, penelitian pendahuluan telah dilakukan untuk menentukan nilai difusivitas panas ( $\alpha$ ) tepung ubijalar varietas Sari pada kisaran kadar air (M) 5,05 – 5,97 % basis basah (bb) dan suhu (T) tepung ubijalar 23,7 – 40,9 °C; dengan menggunakan metode *Dickerson* (1965). Pada kisaran kadar air dan suhu tepung ubijalar tersebut, nilai difusivitas tepung ubijalar mengikuti model  $\alpha = 1E-9 MxT + 9E-09$  ( $R^2 = 0.9794$ ). Nilai rata-rata difusivitas panas tepung ubijalar adalah 1,72E-07 m<sup>2</sup>/s, pada tingkat kadar air tepung 5,51 % bb dan suhu tepung 29,58 °C. Penelitian serupa perlu dilakukan untuk tepung ubijalar dari berbagai jenis varietas unggul ubijalar.

**Kata kunci :** tepung ubijalar, difusivitas panas, metode *Dickerson*

### **ABSTRACT**

In Indonesia, sweet potato (*Ipomoea batatas l.*) is one of carbohydrate sources that can be used for both food and industrial purposes. To support its utilization as flour, it is imperative to develop the drying system that can improve its quality. A preliminary study using an improved variety, namely Sari, was conducted to determine thermal diffusivity ( $\alpha$ ) of its flour, an important parameter in developing drying process. The experiment was run according to *Dickerson* (1965) method using sweet potato flour at different levels of moisture content (M: 5.05 – 5.97 % wet basis) and temperatures (T : 23.7 – 40.9 °C). This method used an apparatus based on transient heat transfer conditions requiring only a time-temperature data. At the levels of M and T studied, the thermal diffusivity of sweet potato flour could be expressed in a linear regression model,  $\alpha = 1E-9 MxT + 9E-09$  ( $R^2 = 0.9794$ ). The average value of thermal diffusivity of sweet potato flour was 1.72E-07 m<sup>2</sup>/s at a moisture level of 5.51 % wet basis and temperature of 29.58 °C. Similar studies are needed for different varieties/cultivars of sweet potato.

**Keywords:** sweet potato flour, thermal diffusivity, *Dickerson* Method

### **INTRODUCTION**

Sweet potato (*Ipomoea 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 Indonesian wheat import which are around 3 million tons annually. From one hectare harvested area, it can be produced 7.50 tons of sweet potato flour. If the total area of sweet potato in Indonesia is 225,000 hectares, 1.70 billion tons of sweet potato flour could be produced per year. Utilization of sweet potato flour for food industries could reduce about 1.40 million tons of imported wheat flour or it is valued at US \$ 302 million per year (Heriyanto *et al.*, 2001).

In relation with food diversification program, processed sweet potato flour has higher value-added (Rp 3,000/kg) compared to roots (Rp 500 /kg) (Heriyanto *et al.*, 2001). However, the quality of sweet potato flour sold at local market is low due to the lack of drying and there are no information on its moisture content and expiry date.

Therefore, it is necessary to improve sweet potato flour through improvement in its drying, milling and packaging systems.

An important physical parameter in drying process of sweet potato flour 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, temperature, composition as well as porosity of the material (Anon., 2002).

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

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

where  $\alpha$  is thermal diffusivity ( $m^2/s$ ),  $k$  is thermal conductivity ( $W/m K$ ),  $\rho$  is density ( $kg/m^3$ ) and  $C_p$  is specific heat ( $kJ/kg K$ ).

The indirect approach is not favored because it requires considerable time and complicated instrumentation for measuring the values of  $k$ ,  $\rho$ , and  $C_p$  (Singh, 1982). Meanwhile, reliable value of  $k$  is limited in the literature and sometime is difficult to be determined 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 a 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 and numerical methods, this study was conducted to determine thermal diffusivity of sweet potato flour which was a function of moisture content and temperature using the transient method 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

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

The experiment was setup (Fig. 1) according to the Dickerson method consisting 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, a 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:

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

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 ( $\theta$ ) dependent in Eq. (2),  $\partial^2$  can be changed to  $d^2$  with the following solution:

Letting surface and center temperatures be  $T_s$ , and  $T_c$  for the boundary condition of

$$T + A\theta = T_s \quad \theta > 0, r = D/2$$

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

The solution red

Taking  $r = 0$   $(T_s - T) = \frac{A}{4\alpha} ((D/2)^2 - r^2)$

$$\alpha = \frac{A D^2}{16 (T_s - T_c)} \dots\dots\dots (3)$$

where  $T_s$  and  $T_c$  are the outside surface of cylinder and sample center temperatures, respectively. D is the external diameter of the cylinder (Fig. 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 and 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 was equal. The sample was then taken out for moisture content determination. This procedure was replicated four times to randomly determine  $\alpha$  at different temperatures (T) and moisture contents (M).

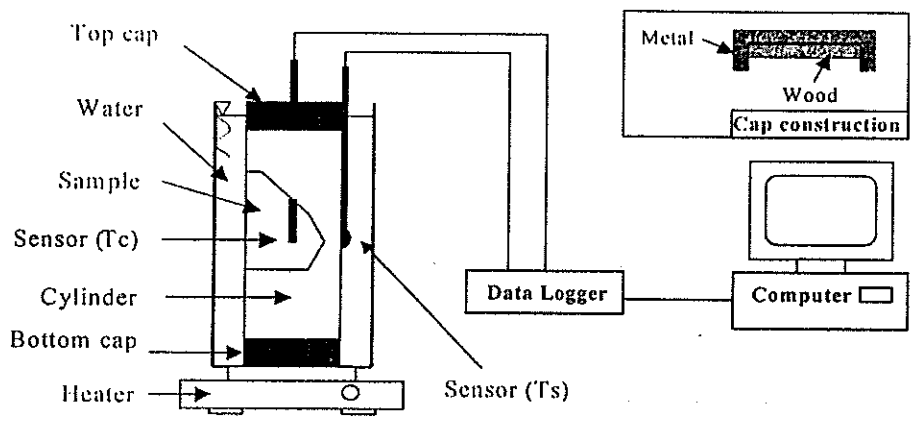


Fig. 1: Apparatus for direct measurement of thermal diffusivity of arrowroot flour (Dickerson, 1965; Tastra, 2004).

To minimize error in determining the value of A and  $(T_s - T_c)$ , which will determine the value of  $\alpha$  (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. Supposed  $T_s$  and  $T_c$  can be expressed as:

$$T_s = B_1 - A_1 \times X$$

And  $T_c = B_2 - A_2 \times X$  ..... (4)

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

$$\alpha = a \times M \times T + b$$
 ..... (5)

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

## RESULTS AND DISCUSSION

### Experimental Values of Sweet Potato Flour Thermal Diffusivity

Experimental time-temperature data of sweet potato flour is a function of moisture content and initial sample center temperatures are illustrated in Fig. 2. 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 ( $\alpha$ ) was determined using Eq. (3) as presented in Table 1. For example, using data on treatment (c) in Fig. 2,  $A = (0.716 + 0.6804)/(2 \times 60)$  ( $^{\circ}\text{C}/\text{s}$ ),  $(B_1 - B_2) = (39.653 - 6.2485)$  ( $^{\circ}\text{C}$ ) and then the calculated  $\alpha = 1.69\text{E-}07$  ( $\text{m}^2/\text{s}$ ).

Table 1: Sweet potato thermal diffusivity ( $\alpha$ ) at different moisture contents ( $M$ ) and initial sample center temperatures ( $T$ ), calculated based on data in Fig. 2.

Treatment	M (% (w. b.))	T ( $^{\circ}\text{C}$ )	$B_1 - B_2$ <sup>1)</sup> ( $^{\circ}\text{C}$ )	$A$ <sup>2)</sup> ( $^{\circ}\text{C}/\text{s}$ )	$\alpha$ <sup>3)</sup> ( $\text{m}^2/\text{s}$ )	Average ( $R^2$ ) <sup>4)</sup>
A	5.97	23.7	36.505	0.6599	1.46E-07	0.996
B	5.46	24.5	38.252	0.7038	1.48E-07	0.993
C	5.56	29.2	33.4045	0.6982	1.69E-07	0.998
D	5.05	40.9	30.032	0.8411	2.26E-07	0.983
Average	5.51	29.6			1.72E-07	0.992

- 1) Intercept differences (Eq. 4) of linear regression of surface ( $T_s$ ) and sample center ( $T_c$ ) temperature
- 2) Average linear regression coefficient of surface ( $T_s$ ) and sample center ( $T_c$ ) temperature multiplied by conversion factor (1/60) to convert unit  $^{\circ}\text{C}/\text{min}$  to  $^{\circ}\text{C}/\text{s}$
- 3) Calculated based on Eq. (3) at external cylinder diameter ( $D$ ) of 0.088 m.
- 4) Average coefficient determination ( $R^2$ ) of regression of surface and sample center temperature, Eq.(4).

The average value of  $\alpha$  was  $1.72\text{E-}07$   $\text{m}^2/\text{s}$ , at a moisture content of 5.51 % (w.b.) and sample temperature of  $29.6$   $^{\circ}\text{C}$  with coefficient determination ( $R^2$ )  $> 0.95$  (Table 1). In addition, the homogeneity test of both regression coefficients ( $A_1$ ,  $A_2$ , Eq. (4)) in each treatment (Table 2) showed that the two regression coefficients were homogeneous due to  $t$ -Calculated  $< t$ -Table (5%). In conclusion,  $A_1$  was statistically equal to  $A_2$ . Therefore,  $A$

in Eq.(3) was equal to  $(A1 + A2)/2$ . This implied that, although the cap of the cylinder did not use Teflon as an insulator (Dickerson, 1965), the apparatus (using wood cap as an insulator) used in this study was still reliable. Moreover, the apparatus being developed did not use a stirrer. Therefore, the construction was simpler.

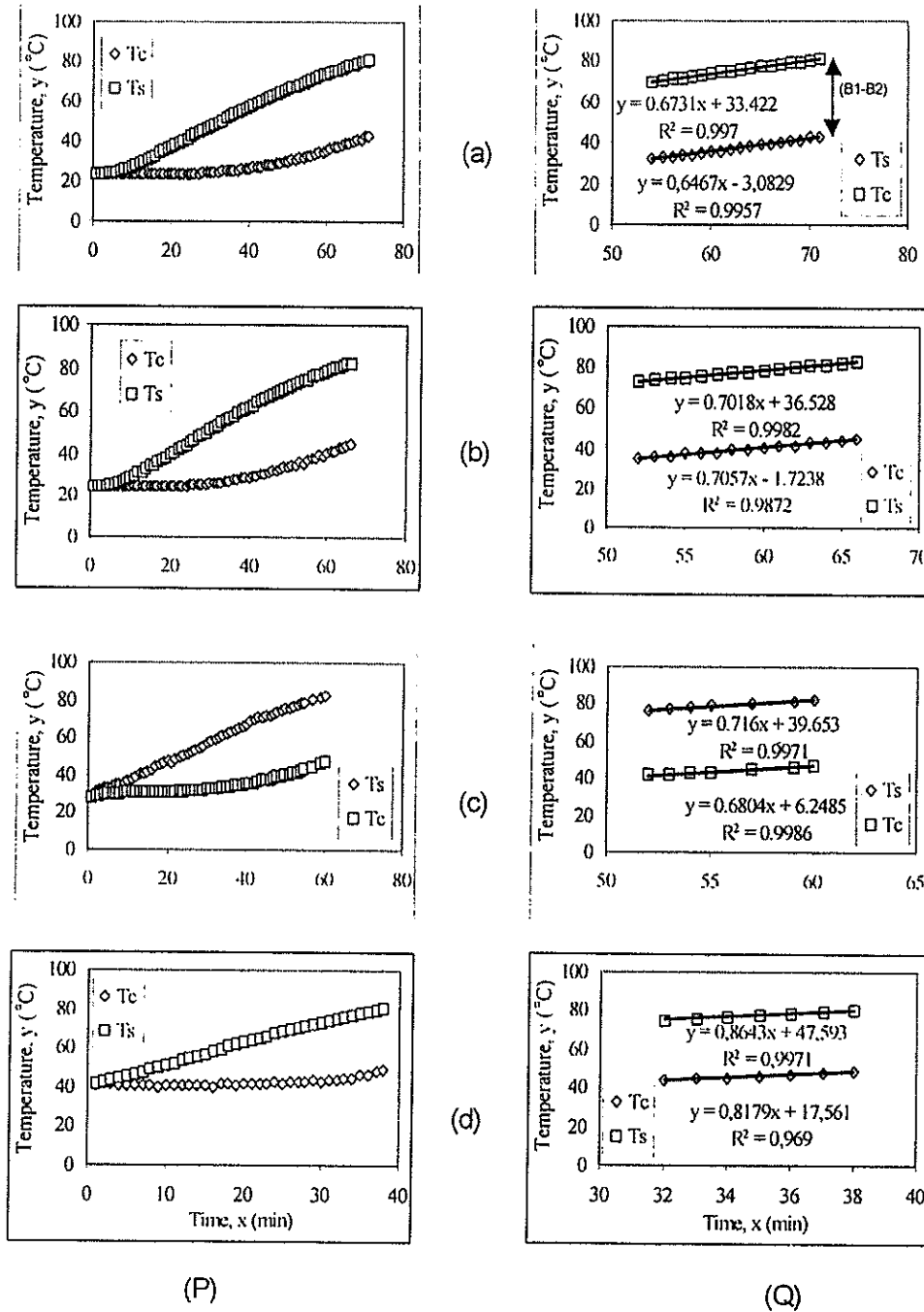


Fig. 2: (P) Measurement of the cylinder surface ( $T_s$ ) and sample center ( $T_c$ ) temperatures at different levels of moisture content ( $M$ ) and temperature ( $T$ ) of Sweet potato flour (a)  $M = 5.97\% \text{ w.b.}, T = 23.7\text{ }^{\circ}\text{C}$ ; (b)  $M = 5.46\% \text{ w.b.}, T = 24.5\text{ }^{\circ}\text{C}$ ; (c)  $M = 5.56\% \text{ w.b.}, T = 29.2\text{ }^{\circ}\text{C}$ ; (d)  $M = 5.05\% \text{ w.b.}, T = 40.9\text{ }^{\circ}\text{C}$  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 2. Summary of the homogeneity test of regression coefficients in Fig. 2 (Q) (Gomez and Gomez, 1984).

Treatment	Moisture content, M (% w. b.)	Temperature, T (°C)	Regression coefficient		t-Table (5%)		t-Calculated	Remark
			A1 <sup>1)</sup>	A2 <sup>1)</sup>	d.f. <sup>3)</sup>	value		
A	5.97	23.7	0.6731	0.6467	32	2.04	-1.86	n.s. <sup>2)</sup>
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 were 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 (Fig. 2 (Q)).

### The Effect of Moisture Content and Temperature on Sweet Potato 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 sweet potato flour can be expressed as  $\alpha = 1E-9 MxT + 9E-09$  with coefficient determination  $R^2 = 0.9794$  (Fig. 3). Therefore, at relatively high coefficient determination ( $R^2 > 0.95$ ), thermal diffusivity of sweet potato flour can be expressed as a function of moisture content and temperature. This agreed with the multiple regression analysis on 246 published values on thermal diffusivity of a variety of food products which was also a function of moisture content and temperature (Martens, 1980 in Hassan and Hobani, 2001). He obtained an equation of thermal diffusivity as  $\alpha = [0.057363 \times X_w + 0.000288 \times (T+273)] \times X_w$ , where  $X_w$  is the sample water content as a weight fraction and T is the sample temperature, °C. The average value of the tested temperature range, i.e. 45 °C was used in estimating the thermal diffusivity. Tastra (2004) also found the same trend in measuring thermal diffusivity of arrowroot flour as a function of moisture content and temperature. However, the homogeneity test showed that the effect of moisture content and temperature was significantly different for sweet potato flour and arrowroot flour (Fig. 4). This was due to the higher moisture content of arrowroot flour (12.9 % w.b.) than that of sweet potato flour (5.51 % w.b.).

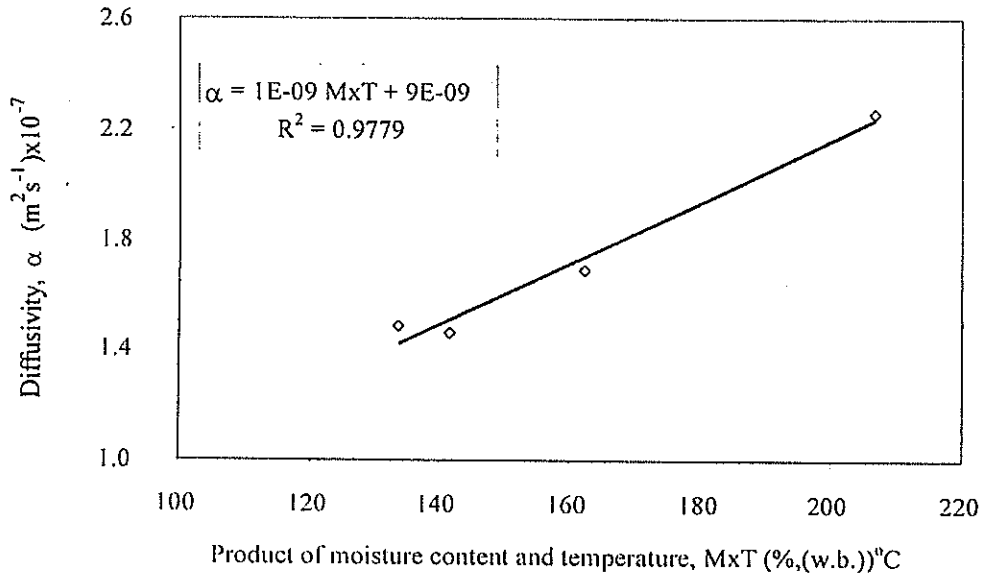


Fig. 3. Diffusivity of sweet potato flour as a function of moisture content (M) and temperature (T).

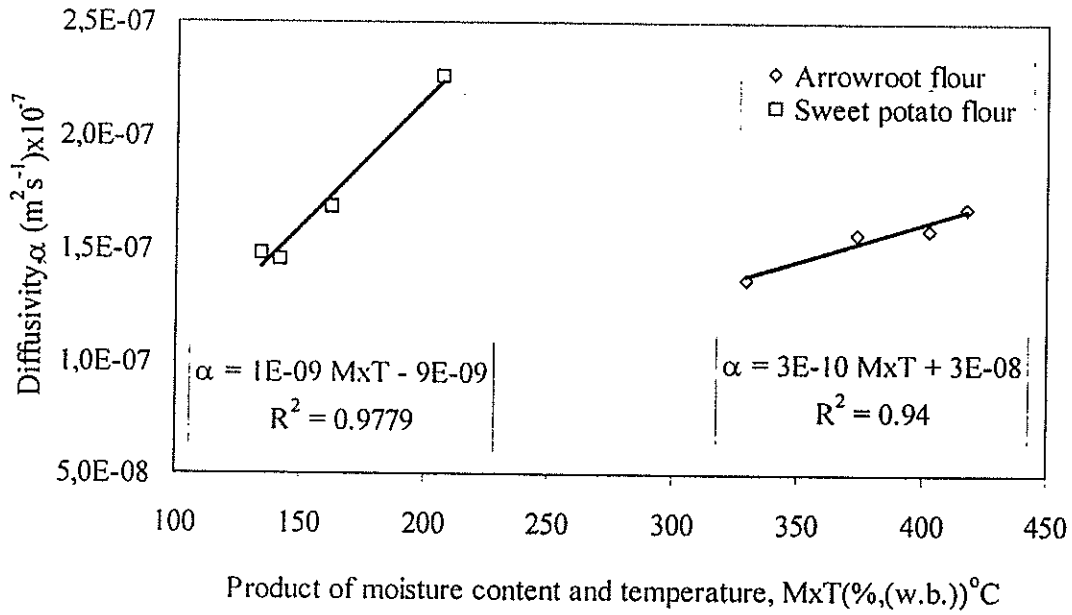


Fig. 4. Homogeneity test the coefficient linear the diffusivity of sweet potato and arrowroot flour as a function of temperature ( $t$ -calculated : 6.17 >  $t$ -Table (0,05; 4) : 2.78).

## CONCLUSIONS

1. Based on this study thermal diffusivity of sweet potato flour can be expressed as  $\alpha = 1E-9 MxT + 9E-09$  ( $R^2 = 0.9794$ ) for the moisture content range of 5.05 – 5.97 % (w.b.) and temperature range of 23.7 – 40.9 °C.
2. The average value of thermal diffusivity of sweet potato flour was found to be  $1.72E-07$  m<sup>2</sup>/s, at moisture content of 5.51 % (w.b.) and temperature of 29.58 °C.

## ACKNOWLEDGEMENTS

The author wishes to thank to Mugiono, Wijiyono and Suprpto, Technical Staff of Post Harvest and Mechanization section, ILETRI, Indonesia, for their helps in fabrication of the equipment and measurements.

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