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A Study on the Thermal Diffusivity of Rectangular and Cylindrical Potatoes

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INTRODUCTION

In order to obtain the optimum design and operating in the various equipments and processes, it is necessary to determine the thermal diffusivity of the food materials.

In previous papers, we have studied the thermal diffusivity of spherical root vegetables[1], potato slabs[2], and egg yolk and white gels[3]. As for softish food materials such as fish and meat, we can not cut them into spherical shape specimens, as shown in the first paper[1], therefor, we have studied for the slab shape specimens, as shown in the second paper[2], by using potato samples that had uniform tissue and physical properties for the wide portions. For gel foods that could not be cut into slab shape, we have taken for study a simple slab container method, as shown in the third paper[3], using egg yolk and white gels.

The results in the second paper are very scattered. The reason is that it is difficult to insert the top point of the thermocouple into the center of the thin slabs. Now, in the present paper, we took up the study of the thermal diffusivity in cylindrical and rectangular materials under various conditions. For this we used potato samples.

THEORITICAL CONDITIONS

1. Heat-conduction equations

The general heat-conduction equations for the various well known shapes are given in various textbooks and so on[4,5] as follow:

Sphere:

$$\partial t/\partial\theta = \alpha[\partial^2 t/\partial r^2 + (2/r)\cdot(\partial t/\partial r)] \tag{1}$$

Infinite slab:

$$\partial t/\partial\theta = \alpha(\partial^2 t/\partial x^2) \tag{2}$$

Rectangular:

$$\partial t/\partial\theta = \alpha(\partial^2 t/\partial x^2 + \partial^2 t/\partial y^2 + \partial^2 t/\partial z^2) \tag{3}$$

Infinite cylinder:

$$\partial t/\partial\theta = \alpha[\partial^2 t/\partial r^2 + (1/r)\cdot(\partial t/\partial r)] \tag{4}$$

Short cylinder:

$$\partial t/\partial\theta = \alpha[\partial^2 t/\partial r^2 + (1/r)\cdot(\partial t/\partial r) + \partial^2 t/\partial z^2] \tag{5}$$

where, $\alpha = k/(C_p \cdot \rho)$ (6)

where, t(°C) is the temperature, θ(min) is the processing time, r(cm) is the distance from the center point or axis, x, y and z (cm) are the distances from the surface in the thick, width and length directions, respectively. α (cm^2/min) is the thermal diffusivity, k(cal/cm·min·°C) is the thermal conductivity, C_p (cal/g·°C) is the specific heat, and ρ (g/cm^3) is the dencity.

It is possible to obtain the value of α in Eqs. (1) ~ (5) by employing the dimensionless heating curves developed by GURNEY and LURIE [4-7], HEISLER [8-10] and others or by employing the tables made up by OLSON and SCHULTZ [11] and others.

However, the numerical calculation method which uses the digital computer program including the non-linear least square method[12] is more accurate and more useful than the methods which used figures or tables. In former papers[1,2], we studied the thermal diffusivity for the spherical and the infinite slab, respectively. In this paper, we study the other shapes in Eqs. (3) ~ (5). In order to simplify and to obtain more accurate results, we studied the specimens under most simple initial and boundary conditions.

For the following simple conditions, we introduced the analytical solutions used for spherical and infinite slab shapes[1,2]. The other ones too have been developed in various textbooks and so on[13,14].

Rectangular:

Initial condition;

$$\theta = 0,\quad 0 \leqq x_c \leqq L_x,\quad 0 \leqq y_c \leqq L_y,\quad 0 \leqq z_c \leqq L_z,\quad : \ t = t_0$$

Boundary condition;

$$\theta \geqq 0,\quad x_c = L_x,\quad y_c = L_y,\quad z_c = L_z,\quad : \ t = t_e$$

$$\theta \geqq 0,\quad x_c = \infty,\quad y_c = \infty,\quad z_c = \infty,\quad : \ t = t_0$$

$$Y = (8/\pi^2)\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{p=0}^{\infty}\Big\{\Big\{(-1)^{m+n+p}/[(m+0.5)(n+0.5)(p+0.5)]\Big\}\cdot\cos[(m+0.5)\pi x_c/L_x]\cdot\cos[(n+0.5)\pi y_c/L_y]\cos[(p+0.5)\pi z_c/L_z]\cdot\exp\Big\{-[(m+0.5)^2/L_x{}^2+(n+0.5)^2/L_y{}^2+(p+0.5)^2/L_z{}^2]\pi^2\alpha\theta\Big\}\Big\} \tag{7}$$

Infinite cylinder:

Initial condition;

$$\theta = 0,\quad 0 \leqq r \leqq R \quad : \ t = t_0$$

Boundary condition;

$\theta \geqq 0, \quad r = R \quad : \quad t = t_e$

$\theta \geqq 0, \quad r = 0 \quad : \quad \partial t / \partial r = 0$

$\theta = \infty, \quad 0 \leqq r \leqq R \quad : \quad t = t_e$

$$Y = (2/R)\sum_{n=1}^{\infty}\left\{[J_0(k_n r)/k_n J_1(k_n R)] \cdot \exp(-\alpha k_n^2 \theta)\right\} \quad (8)$$

where, $Y = |(t - t_e)/(t_0 - t_e)|$ (9)

$x_c = L_x - x, \quad y_c = L_y - y, \quad z_c = L_z - z,$

where, L_x, L_y and L_z (cm) are the half of the thick, width and length of rectangular, R(cm) is the radius of cylinder, and t_0 and t_e (°C) are the initial and terminal temperatures. J_0 and J_1 are the Bessel functions of first kind of zeroth and first order, respectively. Y(-) is the dimensionless temperature which changes $Y=1 \rightarrow 0$ with respect to $t = t_0 \rightarrow t_e$.

It is possible to apply the results for infinite objects to finding the temperature distributions in finite objects[7,9,15]. This may be done by considering the finite object to be formed from the intersection of two or more infinite objects. A finite slab (rectangular) is formed from the intersection of three mutually perpendicular infinite slabs, and a finite cylinder (short cylinder) is formed from the intersection of an infinite slab with an infinite cylinder.

For rectangular:

$$Y = Y_x \cdot Y_y \cdot Y_z \quad (10)$$

For short cylinder:

$$Y = Y_r \cdot Y_z \quad (11)$$

where, Y_x, Y_y and Y_z (—) are the results for the infinite slab in the x, y and z directions, and Y_r (—) is the results for the infinite cylinder. The analytical solution for the infinite slab which can be obtained Y_x, Y_y and Y_z in Eqs. (10) and (11) has been presented in a previous paper[2]. The value of Y_r can be obtained by Eq. (8).

2. Calculation of thermal diffusivity

A computer program using a non-linear least square method[12] was used. The basic flow chart of the program is the same as in the previous papers[1,2]. The values of the following standard deviation σ (—) for the Y were minimized.

$$\sigma = [\sum_{i=1}^{n}(Y_{obs} - Y_{cal})_i^2 / N]^{0.5} \quad (12)$$

where, Y_{obs} and Y_{cal} are the observed and calculated values of Y, and N is the total number of the experimental points. For the calculation of α, we used the digital electronic computers of FACOM M-200 (Nagoya University) and HITAC M-200H (Hiroshima University).

The dimensionless heating curves for finite objects have been given by Newman[15], Dickerson and Read[16] etc. The central temperature histories in a rectangular and a short cylinder and so on are shown in Fig. 1. In Fig. 1, the curves for a sphere and an infinite

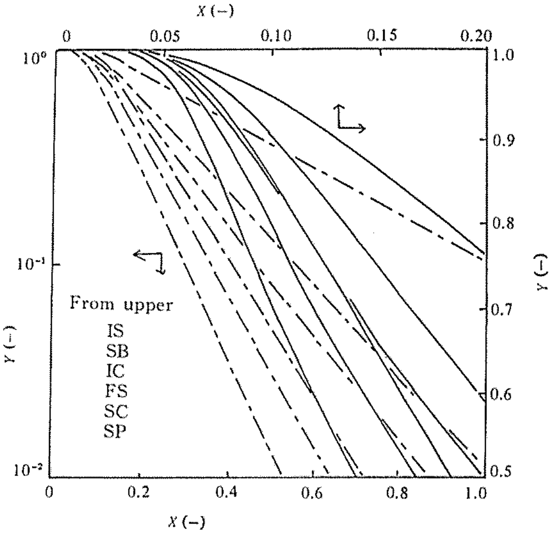

Fig. 1. Central temperature histories in a rectangular and a cylinder
IS: infinite slab ($L_y=\infty$, $L_z=\infty$)
SB: square bar ($L_x=L_y$, $L_z=\infty$)
IC: infinite cylinder ($L_z=\infty$)
FS: cube ($L_x=L_y=L_z$)
SC: short cylinder ($R=L_z$)
SP: sphear

slab have been presented already in previous papers[1,2]. As for the higher values of X, this chart is inaccordance with the results obtained by Dickerson and Read etc.[4,16]. The dimensionless time $X(-)$ in Fig. 1 can be expressed in the following equation.

$$X = \alpha\theta / D^2 \tag{13}$$

where, D(cm) is the half of the thick, width and length or the radius of the objects.

The value of α can be obtained by using these curves in Fig. 1, but this method for the finite objects is complicated because that we must assume the value. It also lacks sufficient accuracy. Therefore, the numerical calculation method which a digital computer is used, is more efficient and more accurate.

For the comparing of the simple infinite calculations on the finite slabs and cylinders, the supposed data were set up on the various finite objects with a thermal diffusivity of $\alpha = 1.0$ cm^2/min. The values of α were calculated from the supposed data by assuming the infinite objects. The initial values of α were given as 0.05 cm^2/min in accordance with the previous papers[1,2]. The results are shown in Table 1 and Fig. 2.

From the Table 1 and Fig. 2, we may infer the following results. In order to obtain better results by assuming the simple infinite calculations on the finite slabs and cylinders, the values of (L_y and L_z)/L_x and L_z/R must be set up at nearly over six and five, respectively.

Table 1. Results for the comparing of infinite calculations on the supposed finite data
Suposed data: Rectangular of L_X, L_Y, L_Z (cm)
assumed α = 0.1 cm^2/min
Calculation: Infinite slab of L_X (cm), $L_X = \infty$, $L_Z = \infty$

Run	L_X (cm)	L_Y and L_Z (cm)	Initial value		Calculated value	
			α (cm^2/min)	σ (–)	α (cm^2/min)	σ (–)
S1	2	∞	0.05	0.201	0.100	0.0001
S2	2	6	0.05	0.209	0.102	0.0060
S3	2	5	0.05	0.221	0.106	0.0120
S4	2	4	0.05	0.250	0.113	0.0222
S5	2	3	0.05	0.314	0.134	0.0355
S6	2	2	0.05	0.447	0.207	0.0398

Supposed data: Short cylinder of R, L_Z (cm) assumed α = 0.1 cm^2 /min
Calculation: Infinite cylinder of R (cm), $L_Z = \infty$

Run	R (cm	L_Z (cm)	Initial value		Calculated value	
			α(cm^2/min)	σ (–)	α (cm^2/min)	σ (–)
S7	2	∞	0.05	0.203	0.100	0.0001
S8	2	6	0.05	0.206	0.100	0.0004
S9	2	5	0.05	0.207	0.100	0.0010
S10	2	4	0.05	0.209	0.101	0.0030
S11	2	3	0.05	0.226	0.104	0.0082
S12	2	2	0.05	0.288	0.121	0.0155

Supposed data : Short square bar of L_X, L_Y, L_Z *(cm) assumed* α = 0.1 cm^2 /min
Calculation : Infinite square bar of L_X, L_Y (cm), $L_Z = \infty$

Run	L_X and L_Y (cm)	L_Z (cm)	Initial value		Calculated value	
			α (cm^2/min)	σ (–)	α (cm^2/min)	σ (–)
S13	2	∞	0.05	0.273	0.100	0.0003
S14	2	6	0.05	0.273	0.100	0.0006
S15	2	5	0.05	0.275	0.100	0.0018
S16	2	4	0.05	0.280	0.101	0.0055
S17	2	3	0.05	0.299	0.106	0.0134
S18	2	2	0.05	0.365	0.127	0.0194

Table 2. Results for the thermal diffusivity and standard deviation respected interation number on the supposed data.

Supposed data : Run S7 in Table 1

K	α (cm^2/min)	σ (–)
0	0.05	0.2096
1	0.0644	0.1263
2	0.0817	0.0568
3	0.0945	0.0156
4	0.0992	0.0021
5	0.1000	0.0002
6	0.1000	0.0001

where, K : number of iteration (–)

The results for the thermal diffusivity and standard deviation respecting iteration number are shown in Table 2. From this Table 2, we may infer that the better results can

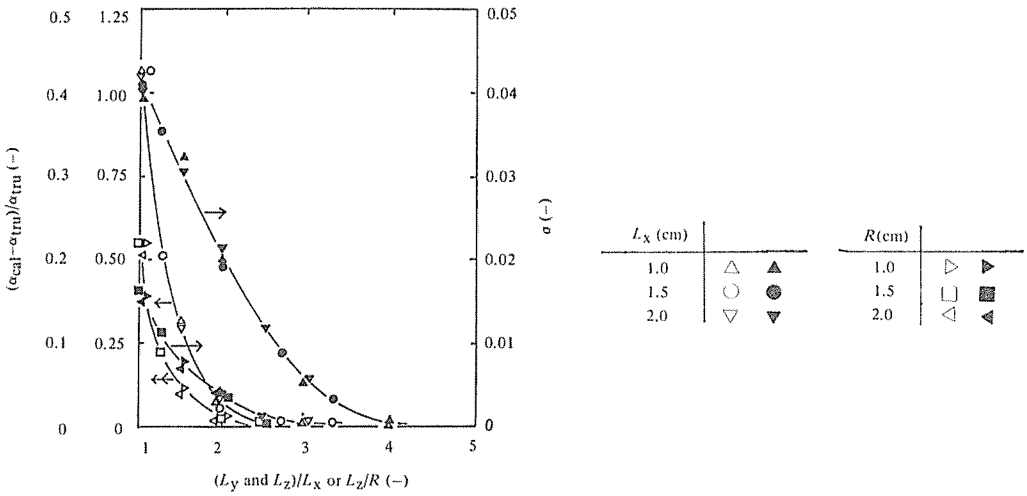

Fig. 2. Comparing of infinite calculations on the supposed finite data

be obtain on the iteration number around six. This result of nearly six is about the same as the one in the previous papers[1,2].

EXPERIMENTAL

1. Samples

As samples, we used potatoes bought in the market. Their variety and specific descriptions: May Queen and twice large size, which names were given by the Agricultural Co-Operative Association of Obihiro, Hokkaido. The reason for selecting particularly potato is that large size samples, homogeneous in regard to condition heat transfer and large samples can be obtained all seasons in Japan.

Table 3. Samples and experimental conditions

Sample : Rectangular potatoes

Run	Dimension (cm)	Thermocouple	Run	Dimension (cm)	Thermocouple
1	20.6 x 21.0 x 49.6	S, U	6	19.6 x 21.0 x 48.6	S, E
2	19.2 x 20.6 x 38.7	S, U	7	20.0 x 20.4 x 38.6	S, E
3	20.0 x 20.0 x 20.0	S, U	8	20.3 x 20.6 x 20.6	S, E
4	24.8 x 25.0 x 25.0	S, U	9	24.8 x 25.0 x 25.0	S, E
5	33.6 x 34.3 x 42.2	S, U	10	27.8 x 28.7 x 35.5	S, E
11	20.6 x 21.0 x 49.6	T, E	14	20.3 x 20.6 x 20.6	T, E
12	20.0 x 20.4 x 38.6	T, E	15	24.8 x 24.8 x 25.0	T, E
13	20.6 x 20.6 x 30.6	T, E			

Sample : Cylindrical potatoes

Run	Dimension (cm)	Thermocouple	Run	Dimension (cm)	Thermocouple
16	20.2 x 50.0	S, U	20	20.2 x 49.8	S, E
17	20.2 x 40.0	S, U	21	20.2 x 39.6	S, E
18	20.2 x 30.0	S, U	22	20.2 x 30.2	S, E
19	20.2 x 21.1	S, U	23	20.2 x 20.8	S, E
24	20.2 x 50.0	T, E	26	20.2 x 30.2	T, E
25	20.2 x 40.3	T, E	27	20.2 x 20.8	T, E

where, Thermocouple:
S type : stainless steel sheath
T type : Teflon sheath
U : Insulator used, E : excepted

The cylindrical and rectangular shape of the samples was made by means of a cork borer and a sharp cutter. For the samples of various size, the comparing experiments were tested in respect to the conductive effect on the measuring temperature. The samples used in this study are shown in Table 3.

2. Apparatus and experimental method

The apparatus used in this study is same as the one shown in previous paper[2]. This apparatus can be found in the basic experimental textbooks[17,18]. The samples were placed in a cool-side or a heat-side water bath which were controlled at 10°C and 50°C, respectively, and then, suddenly put onto the other side one. The center temperature changes of the samples were measured by means of a chromel-alumel thermocouple connected to a recorder.

The two type thermocouples used had been bought in the market. The one type (S type) was that which had two fine wires enclosed in a 1.0 mm diameter stainless steel sheath. The diameter of the chromel and alumel wires were 0.16 mm, respectively, and the thickness of the sheath was 0.15 mm. The interval space in the sheath was filled up with magnesium oxide which packs closely. The other (T type) had two fine wires enclosed in two thin Teflon tubes (diameter 0.6 mm), and the insulated tubes were conbined and enclosed in one thin Teflon outer tube. The diameters of chromel and alumel wires were 0.32 mm. The short and long side diameters of the outer tube were 1.0 and 1.5 mm, respectively. The top point was made by 0.3 mm of uncovered wire and 20 mm length of it was without outer tube.

In some experiments, the thermocouple probe was covered with a cylindrical styrofoam (3.2 cmϕ x 5.0 cm) insulator in order to know the conductive effect through the thermocouple probe. When the insulator was excepted, we used vinyl tape as a stopper at the probe of length L_z(cm). The thermocouples used in this study are shown in Fig. 3.

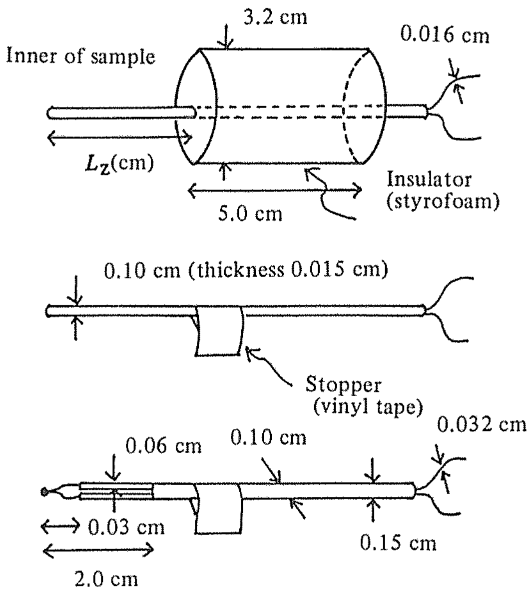

Fig. 3. Thermocouples
(1) Stainless steel sheath used insulator (S,U)
(2) Stainless steel sheath excepted insulator (S, E)
(3) Teflon sheath excepted insulator (T,E)

RESULTS AND DISCUSSION

The relationships between the dimensionless temperature $Y(-)$ and the time θ(min) are shown in Figs. 4 and 5. The all calculated values of α by using Eqs. (10) and (11) are shown in Table 4. The calculated values of α by using Eq. (7) are shown in Table 5. In Tables 4 and 5, the comparing results of α, do not differ very much from mutually. The calculated results used of the obtained values of α shown in Table 4 are visualized by the solid lines in Figs. 4 and 5. All of the calculated results were satisfactory.

Table 4. Calculated results of thermal diffusivity by using Eqs. (10) and (11)

Run	α (cm²/min)	σ (−)	Run	α (cm²/min)	σ (−)
1	0.0829	0.0031	6	0.0873	0.0112
2	0,0803	0.0045	7	0.0894	0.0095
3	0.0689	0.0092	8	0.0897	0.0099
4	0.0734	0.0094	9	0.0892	0.0116
5	0.0847	0.0055	10	0.0876	0.0072
11	0.0842	0.0081	14	0.0862	0.0075
12	0.0842	0.0059	15	0.0850	0.0042
13	0.0882	0.0089			
16	0.0811	0.0039	20	0.0820	0.0061
17	0.0770	0.0033	21	0.0788	0.0032
18	0.0823	0.0021	22	0.0820	0.0040
19	0.0734	0.0126	23	0.0848	0.0050
24	0.0825	0.0086	26	0.0820	0.0052
25	0.0804	0.0062	27	0.0831	0.0041

Table 5. Calculated results of thermal diffusivity by using Eq. (7)

Run	α (cm²/min)	σ (–)	Run	α (cm²/min)	σ (–)
1	0.0828	0.0062	6	0.0872	0.0109
2	0.0803	0.0057	7	0.0894	0.0094
3	0.0689	0.0092	8	0.0897	0.0099
4	0.0734	0.0095	9	0.0892	0.0116
5	0.0847	0.0076	10	0.0876	0.0075
11	0.0841	0.0102	14	0.0862	0.0075
12	0.0842	0.0063	15	0.0850	0.0042
13	0.0882	0.0089			

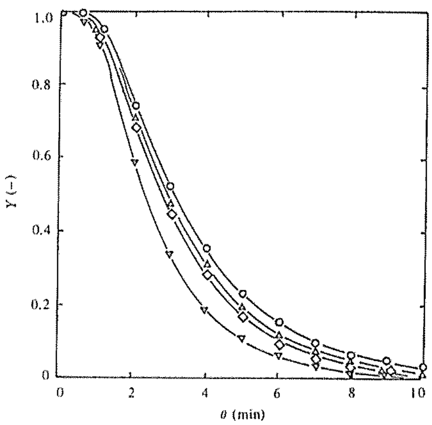

Fig. 4. Relations between dimensionless temperature and process time
Observed results: Run 11 12 14 3
○ △ ▽ ◇
Calculated results: ———

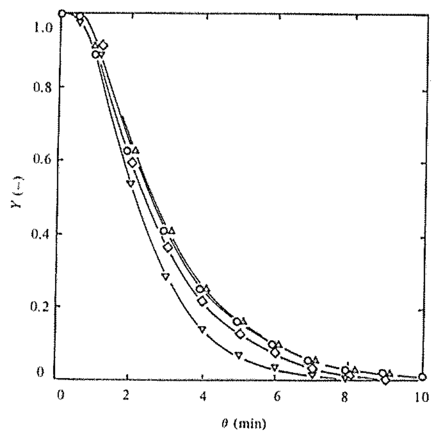

Fig. 5. Relations between dimensionless temperature and process time
Observed results: Run 24 25 27 19
○ △ ▽ ◇
Calculated results: ———

In Figs. 4 and 5, the comparing results of Run 24 and 25 do not differ mutually, but the results of Run 11 and 12 differ. The reason is that the cylindrical samples were could be given a constant radius by using a cork borer, while the rectangular samples could not be given a constant thickness and widthness due to the use of a cutter, as shown in Table 3.

In Figs. 4 and 5 and Table 4, the results of Run 3 and 4 and 19 differ greatly from the others. From the insulated thermocouples, we may infer that when the value of L_z is less than 2.5 cm. the results can not be accurately obtained. This is due to the fact that the heating can not come from the insulated direction.

The models for these cases may be made up by considering the semi-infinite object to be formed from the intersection of infinite and semi-infinite objects. A semi-infinite slab (one surface sealed rectangular) is formed from the inter-section of two infinite slabs and a semi-infinite slab, and a semi-infinite cylinder (one surface sealed short cylinder) is formed from the intersection of a semi-infinite slab with an infinite cylinder.

For one surface sealed rectangular:

$$Y = Y_x \cdot Y_y \cdot Y_{sz} \tag{14}$$

For one surface sealed short cylinder:

$$Y = Y_r \cdot Y_{sz} \tag{15}$$

where, Y_x and Y_y (−) are the results for the infinite slab, Y_r (−) is the results for the infinite cylinder, and Y_{sz} (−) is the results for the semi-infinite slab in the z direction. The value of Y_{sz} in Eqs. (14) and (15) can be obtain by the following equation.

Semi-infinite slab:

Initial condition;

$$\theta = 0, \quad x \geqq 0 \qquad : \quad t = t_0$$

Boundary condition;

$$\theta \geqq 0, \quad x = 0 \qquad : \quad t = t_e$$

$$\theta \geqq 0, \quad x = \infty \qquad : \quad t = t_0$$

where, $$Y = \mathrm{erf}\,(\eta)\ , \quad \eta = L_{sz} / (2\sqrt{\alpha\theta}) \qquad (16),\ (17)$$

where, L_{sz} (cm) is the depth of the considered point in the semi-infinite slab. Erf is the Error function.

The calculated values of α using Eqs. (14) and (15) are shown in Table 6. All of the

Table 6. Calculated results of thermal diffusivity by using Eqs. (14) and (15)

Run	α (cm²/min)	σ (−)	Run	α (cm²/min)	σ (−)
1	0.0831	0.0039	16	0.0812	0.0037
2	0.0811	0.0027	17	0.0774	0.0036
3	0.0783	0.0138	18	0.0835	0.0063
4	0.0829	0.0065	19	0.0794	0.0038
5	0.0895	0.0102			

calculated results are larger than the values obtained in Table 4. The results of Run 3, 4 and 19 change to much larger values and they do not differ much from the other values. In the insulated thermocouple, we may infer that the results can be more accurately obtained by using Eqs. (14) and (15) than by using Eqs. (10) and (11).

In Table 4, the compared results, except those of Run 3, 4 and 19 do not differ greatly from each other. So, we may infer that when the value of L_z is larger than 2.0 cm, the effects for the S and T type thermocouples can be neglected.

The average value of $\alpha = 0.0840$ cm^2/min (except for Run 3, 4 and 19) obtained in this study is proves to be smaller than the 0.097 cm^2/min which was the value determined in the first paper[1]. The reason is that the previous temperature range were higher than that of the present studies.

The value of α in this study is larger than the value of it in the second paper[2]. The reason is that the top point of the thermocouple can not be inserted into the center of the sample in the second paper, because the thickness of the infinite slab was insufficient. In order to be useful as the sample, we may infer that the thickness must have a large value than 1.0 cm.

The values of α in this study are a little scatterd. The reason is that it is difficult to insert the thermocouple into the center of the samples. If highly accurate values are needed, the values of L_x and R must be larger than 1.0 cm.

The values of α in potatoes have been determined as $0.056 \sim 0.085$ cm^2/min by MATTHEWS and HALL[19], and 0.102 cm^2/min by RAO et al[20] etc.

The relationships between the central dimensionless temperature and the processing time for the various rectangular materials of half thickness $L_x = 2.0$ cm, and on the various cylindrical materials of a radius R=2.0 cm for α=0.05, 0.1, 0.15 and 0.2 cm^2/min are shown in Figs. 6 and 7, respectively.

If we obtain the central temperature history of foods in the shapes of Figs. 6 or 7, the

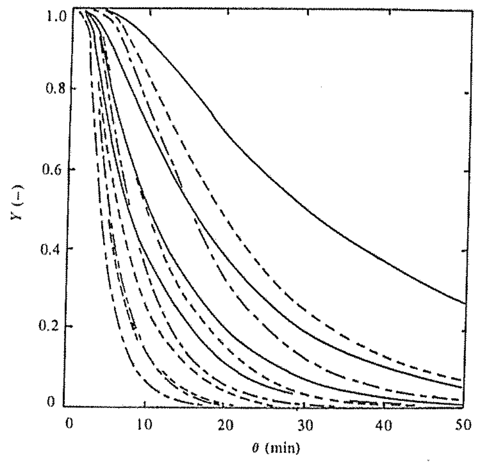

Fig. 6. Temperature history in rectangular materials for various conditions.

Infinite slab : L_x=2.0cm, $L_y=\infty$, $L_z=\infty$ (———)

Square bar : $L_x=L_y$=2.0cm, $L_z=\infty$ (- - - - -)

Cube : $L_x=L_y=L_z$=2.0cm (— - — -)

From upper : α = 0.05, 0.1, 0.15 and 0.2 cm^2/min

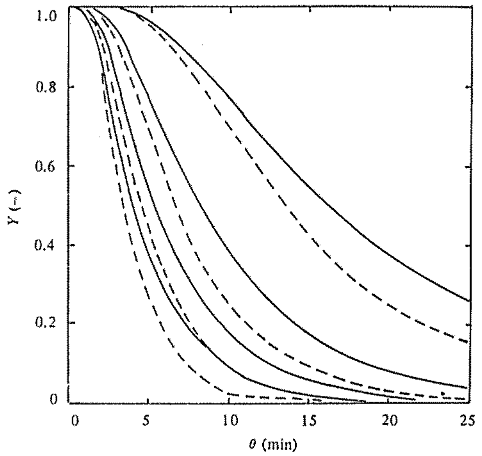

Fig. 7. Temperature history in cylindrical materials for various conditions.

Infinite cylinder : R=2.0 cm, $L_Z=\infty$
———
Short cylinder : R=2.0 cm, L_Z=2.0cm
- - - - -
From upper : α=0.05, 0.1, 0.15 and 0.2 cm²/min

value of α can be determined approximatively by using those figures. The figures for sphere and infinite slab have been presented in previous papers[1,2]. When the values with a high accuracy are required, the digital computering method used in this study is very sueful.

If we can obtain the values of α for various foods by various procedures[21,22], we can obtain the expressions[22,23] which are related to water, fat, protein, carbohydrate contents and temperature.

A part of this paper will be presented on the occasion of the Okayama Meeting of the Society of Chemical Engineers of Japan (17th July, 1985).

SUMMARY

Properties such as thermal diffusivity etc. play an important role in the design and analysis of food processes and processing equipment. In former papers[1-3], we studied the thermal diffusivity for spherical and infinite slab potatoes etc.

In this paper, we took up a similar study for the rectangular and cylindrical potatoes. The values of thermal diffusivity of potatoes are considered to be in average 0.0840 cm^2/min at a temperature range between 10 and 50°C. These results are better than the value of 0.08 cm^2/min that we obtained in a former paper. The reason for this improvement is that the top point of the thermocouple can not be incert into the center of the thin slabs which can be assumed as infinite slab.

The central temperature histories in rectangular and cylindrical materials are shown in different figures. These figures are useful for obtaining the approximate thermal diffusivity from the experimental data.

The digital computering method which used a non-linear least square method in this paper is more accurate and useful than the former methods which used figures or tables.

NOTATION

C_p	:	specific heat (cal/g·°C)
D	:	half thickness, widthness and length or radius (cm)
J_0	:	Bessel function of first kind of zeroth order
J_1	:	Bessel function of first kind of first order
K	:	number of iteration (–)
k	:	thermal conductivity (cal/cm·min·°C)
L_x, L_y, L_z	:	half thickness, widthness and length (cm)
N	:	number of experimental points (–)
R	:	radius (cm)
r	:	distance from the center point or axis (cm)
t	:	temperature (°C)
X	:	dimensionless time (–)
x, y, z	:	distance from surface for the thickness, widthness and length directions (cm)
Y	:	dimensionless temperature (–)
α	:	thermal diffusivity (cm^2/min)
θ	:	processing time (min)
ρ	:	density (g/cm^3)
σ	:	standard deviation (–)

Subscripts;

0 and e : initial and terminal states

obs and cal : obseved and calculated values

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直方体と円柱状ジャガイモの熱拡散率の算出に関する研究

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各種食品を加熱処理するクッキング装置などの設計をするためには，各種食品の熱拡散率を求めておくことが必要となる。前報において，球状[1]，平板状[2]ならびにゲル状[3]食品の熱拡散率の測定に関する研究を行ってきた。

本報では，直方体と円柱状食品の熱拡散率の測定に関する研究をジャガイモを例として行った。ジャガイモの熱拡散率の値は，温度10～50℃において0.0840 ㎠／min となった。平板状食品では，熱電対の先端を試料の中心部に挿入するときの誤差が大きいため，本報で得られた値は，前報[2]で求めた0.08 ㎠／min よりも良い結果である。また，熱電対からの伝熱による誤差を無視できるようにするために発泡スチレンを取りつけたが，この場合には，半無限角柱，半無限円柱状を仮定する計算がよいなどの結果が得られた。

熱拡散率の概算値を得るのに便利な中心温度変化曲線を，前報[1][2]と同様にして，直方体と円柱状試料とに対しても示したが，本報で示した非線形最小二乗法[12]を用いて電子計算機を利用して熱拡散率を算出する方法が精度がよい値が得られることなどから最も優れている方法といえる。