ジャガイモ薄片のマイクロ波加熱におけるクッキング速度式に関する研究

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Study on the Cooking-rate Equations by Microwave Heated Cooking of Potato Slices

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INTRODUCTION

In order to design various cooking apparatuses, it is necessary to measure the cooking rates and establish a cooking rate equation. In previous papers[1,2], we have studied the cooking-rate equations by the hot water dipped cooking of sliced and spherical potatoes. In this paper, we studied the cooking-rate equation by microwave heated cooking of potato slices.

The values of the cooking-rate of the potato slices for hot water dipped cooking could be measured by means of the experimental method consited constant temperature system. However, the experiments for microwave heated cooking must be studied by the temperature unsteady-state system. The determination method of the rate equation is more difficult than the former one. The temperature of the sample can not be measured continuously, because the thermocouple can not be treated in the microwave range. Therefore, we can not see the report according to the cooking-rate equation for microwave heated cooking.

In this paper, the values of the parameters in the rate equation by the unsteady-state system were calculated using a non-linear least square method[3] formed by authors.

The cooking of a potato slice was set up in an electronic range, and the temperatures for the various cooking times were measured by using a thermolabel. The degree of cooking of the potato slices was measured by means of the same rheological method that had been used in a previous paper[4].

EXPERIMENTAL

1. Samples

As samples, we used potato slices. These potatoes were bought from 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, Japan. The reason for selecting this particular potato was that large size samples which are homogeneous in regard to cooking can be obtained in all seasons in Japan. Only the center parts were used as samples. They were cut into slices of 32.5 mm diameter and 3.0 mm thickness with a sharp cutter and a cork borer. The sliced samples were stored for ten minutes in water at 30°C. The weight of the samples used was approximately 2.70 g, and the moisture content was about 7.20 g-H_2O/g-dry material.

2. Microwave heated cooking

Four cut thermolabels were set on the center surface of the stored potato slices, and the labeled samples were bundled loosely in a chloride polyvinylidene sheet of 10 X 10 cm area. The thermolabels (Irreversible type, temperature interval of 5°C, Nichiyu Giken Kogyo Co., Ltd., Japan) could be used for measuring the maximum increased temperature by their color changing, and the bundled sheet (Trade mark: Kure-wrap, Kureha Kagaku Co., Ltd., Japan) could be used to hold the high water content of the samples. The bundled smaple used in our experiments is shown Fig. 1.

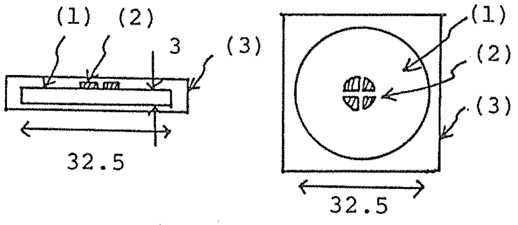


Fig. 1 Sample of potato slice
(1) sample, (2) thermolabel, (3) chloridepolyvinylidene sheet (Kure-wrap).

This bundled sample was put into an electronic range (Type: NE-6330, National Denki Co., Ltd., Japan; 2450 MHz, Input: 1.15 kW, Output: 600, 240, 180 W, Size: 34 X 34 X 18 cm) using an output power of 240 W for a fixed time. This range has a stirring fan which can be stired the generated microwave from a magnetron, and has a large glass dish too that can be turned.

The bundled sample was set on a holder made by a Teflon (polytetrafluoroethylene) thread net which was put on the turned glass dish. This holder was used to avoid the conduction loss of heat to the glass dish set in the range. The teflon thread net system was made by using a thread of diameter: 0.1 mm, (Iuchi Seieido Co., Ltd., Japan) and glass poles. The sample holder system used in our experiments are shown in Fig. 2. The bundled sheet could be used to hold the increased surface temperature of samples as well as to hold the produced water vapor, and to avoid the convection loss of heat.

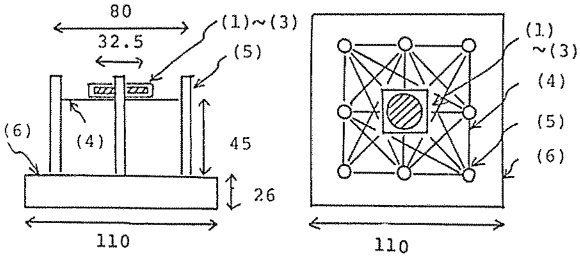


Fig. 2 Sample holder used in the electronic range
(1) sample, (2) thermolabel, (3) chloridepolyvinylidene, (4) Teflon thread, (5) glass poles, (6) styrofoam

One test tube adding water of 10 cc was used to avoid the overheat of the range. The initial temperature of water was 30°C. The tube added water is shown in Fig. 3. This was put on the other part of the sample holder on the turned glass dish.

The sample was cooked on the turned glass dish for a fixed time. The cooked potato slice was taken out from the range, and then was quickly removed from the bundled sheet and put into water of 30°C for one minute, in order to stop further cooking.

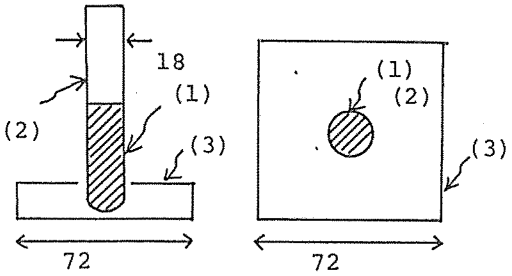


Fig. 3 Test tube added water
(1) water, (2) test tube, (3) styrofoam

The maximum increased temperature of the sample was measured by the color changing of four thermolabels which could be used for different temperatures. After that the surface water was wiped away and the rheological value was measured by the method as shown latter.

By this method the errors of the observed values remained large. Therefore, we repeated the experiment ten times for each run. The observed values used in this paper are the average values.

3. Texture measurements

Textural properties of various foods have been evaluated, usually by rheological tests such as compression, extension, penetration and so on. The rheological properties are very useful means for the elucidation of the cooking of foods. For these purposes, Texturometer, Rheolometer, Tensipresser and so on are very useful, because these instruments supply reliable and broad rheological data. However, they are very expensive for obtaining the operating properties in the cooking of foods.

In previous papers [1,2], we studied an impact-penetration tester which is much cheaper textural instrument. However, this instrument can be used only for measuring the impact-penetrating data of thin soft solid foods.

Therefore, we had to design a new instrument[4] which can be used for thick hard solid foods too. This instrument is rather simple, and therefore, the creep and relaxation data could not be obtained accurately. However, it is useful for determining the various operating properties such as the tensile, shear properties and so on, by changing the crosshead and the sample support plates.

As this instrument is cheap, it can be used in the sensorial parts of the food processing. In this study, the degree of cooking of the potato slice was measured by means of the constant velocity penetration method. The test requires a plunger and a sample holder.

The diameter of the plunger is 3 mm, and is moved with a constant velocity of 2.65 cm/min by using a synchronous motor, a gear head and a screw shaft. The sample holder, made of two acrylate plates of 0.9 cm thick have a hole of 1.0 cm diameter which can be let pass through the plunger without touching each other. The sample is held tightly between the two plates. A load cell was set under the fixed plate. This cell was connected to a strain amplifier, and finally to a voltage recorder. The force or weight of samples can be obtained on the recorder. The sample holder and the plunger used in this rheological test are shown in Fig. 4.

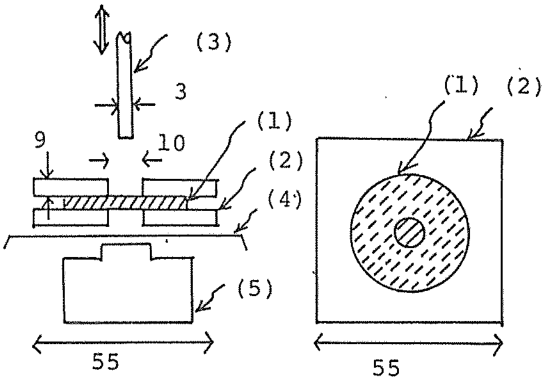


Fig. 4 Sample holder and plunger uned in the constant velocity penetration method (1) sample, (2) holder plate, (3) plunger, (4) fixed plate, (5) load cell

The force-time curves of the cooked samples were observed for a fixed cooking time. These results are shown in Fig. 5. In Fig. 5, the cooking ratio $x(-)$ was obtained as follows:

$$x = (W_0 - W)/(W_0 - W_e)$$

where, W(g) is the weight by using the load cell. Subscripts o and e show the initial and equilibrium states. The solid and broken curves in Fig. 5 are the calculated results as shown latter.

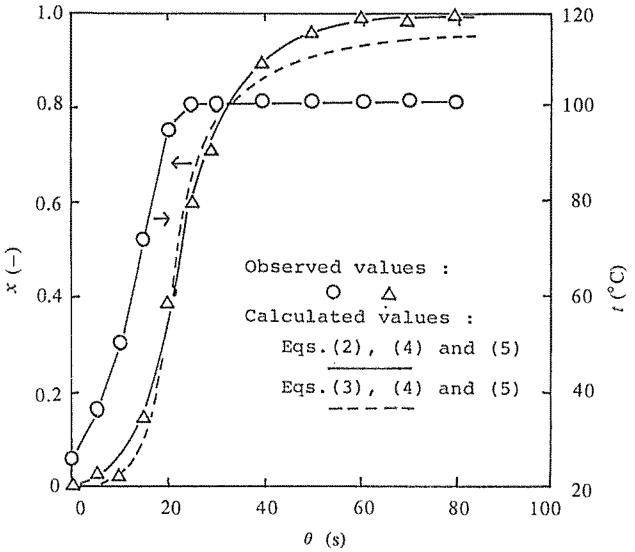


Fig. 5. Relation between the cooking ratio x and temperature t, and the cooking time θ for the cooking of potato slices.

RATE EQUATIONS AND DISCUSSION

1. Rate equations

The changes of the operating properties on the cooking of foods can be expressed in the following rate equations[5].

nth-order rate equation:

$$dx/d\theta = k(1-x)^n \qquad (2)$$

S-shape rate equation:

$$dx/d\theta = k\,(1-x)^n\,(x+\alpha) \tag{3}$$

Arrhenius type equation:

$$k = A\exp(-E/R_g\,T) \tag{4}$$

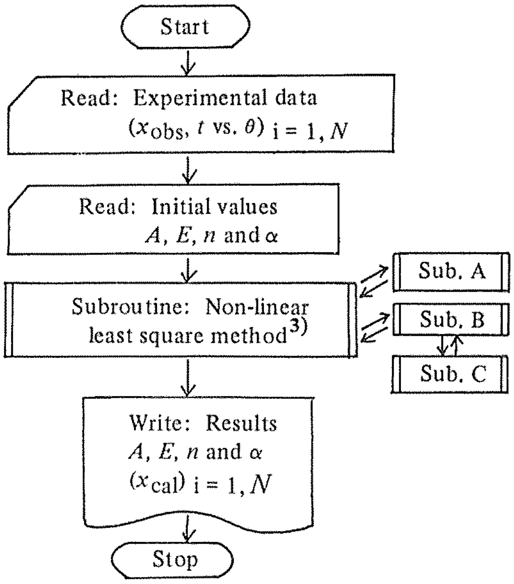
$$T = t + 273.2 \tag{5}$$

where, both T (°K) and t (°C) are the cooking temperature and R_g = 1.987 cal/mol·°K is the gas constant. k, n, α, A and E are the parameters which can be obtained from the data of x, t vs. θ. The values of n and α are interesting, because these values indicate the form of the curves.

The rate equations were integrated numerically using the Runge-Kutta-Gill method, and the rate parameters were calculated by a non-linear least square method[3]. The values of the following standard deviation $\sigma(-)$ for the variable x were minimuzed.

$$\sigma = [\sum_{i=1}^{n}(x_{\mathrm{obs}} - x_{\mathrm{cal}})_i^2 / N]^{0.5} \tag{6}$$

where, x_{obs} and x_{cal} are the observed and caluclated values of x, and N is the total number of data. The simplified flow chart is shown in Fig. 6.



where,
Sub. A; Subroutine for calculation of simultaneous linear equation
Sub. B; Subroutine for calculation of ordinary differential equation
Sub. C; Subroutine of rate equations of Eqs.(2), (4) and (5) or Eqs.(3), (4) and (5)

Fif. 6 Flow chart for calculation of non-linear rate parameters.

For the calculation of parameters, we used the digital electronic computers of FACOM M-200 (Nagoya University) and HITAC M-200H (Hiroshima University).

2. Calculated results

The caluculated values of rate parameters A, E, n and α in Eqs.(2) ~ (4) and the standard deviations σ are listed in Table 1. The orders of these parameters are very different, therefore these parameters must be calculated by using a weighing factor. The parameters were based on the values of log A, $E \times 10^4$, n and α which were nearly of the same order.

Table 1 Calculated results of the parameters A, E, n and α and the standard deviation σ for microwave heated cooking

For Eq.(2), (4) and (5) :

$A(s^{-1})$	E(cal/mol)	$n(-)$	$\sigma(-)$
2.03×10^5	1.07×10^4	1.15	0.021
5.09×10^4	9.80×10^3	1.0 (fixed)	0.023

For Eq. (3), (4) and (5) :

$A(s^{-1})$	E(cal/mol)	$n(-)$	$\alpha(-)$	$\sigma(-)$
4.10×10^8	1.75×10^4	1.81	8.73	0.045
7.78×10^{12}	2.42×10^4	2.0 (fixed)	5.37	0.056

The values of n in Eq.(2) and Eq.(3) are bound to be about 1.0 and 2.0, respectively. Therefore, the calculated values of A, E and α which fixed n, and the values of σ, are listed in Table 1, too.

The calculated values of x for the obtained parameters in Table 1 are shown by the curves in Fig. 5. The solid and broken curves in Fig. 5 are the calculated results for Eq.(2) and Eq.(3), respectively.

The results for the rate parameters and the standard deviation in respect to the iteration number are shown in Fig. 7. Fig. 7 is the results for Eq.(2). From this Fig. 7, we may infer that the best results can be obtained on an iteration number of around fifteen. This result of nearly fifteen is not the same as the result of nearly five in the previous paper[2]. The difference is that the values of A, E are more affected by the values of n and α than the value of thermal diffusivity in the previous paper[2].

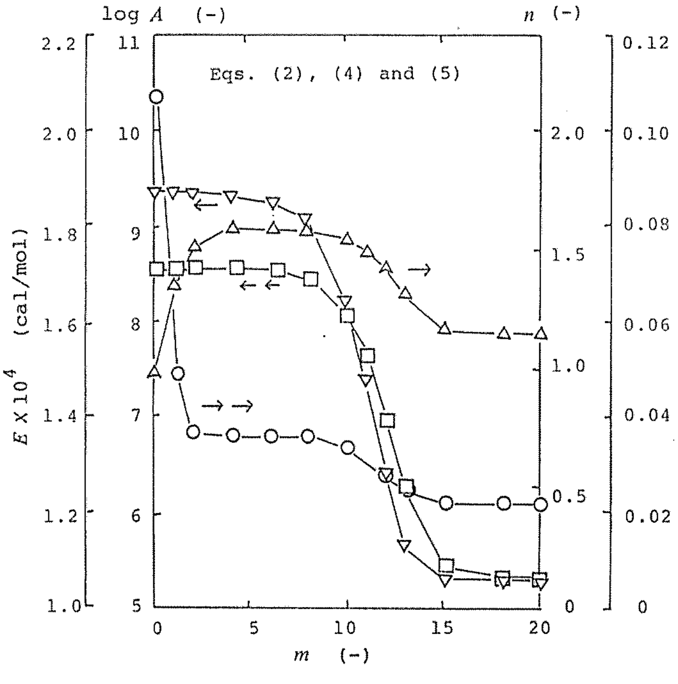


Fig. 7 Relation between the rate parameters log A, $E \times 10^4$, n and standard deviation σ and the iteration number m for the cooking of potato slices

The value of the standard deviation σ for Eq.(2) in Table 1 is smaller than the one for Eq.(3). The calculated results of Eq.(2) are satisfactory enough. Therefore, we may infer that the S-shape relations of the cooking ratio x to the cooking time θ, which were obtained for the condition of the temperature unsteady-state system can be expressed by using Eq.(2) which is much simpler than Eq.(3).

The calculated values of A, E and α for the hot water dipped cooking of potatoes in the previous papers[1,2,6] are listed in Table 2. From the comparision of Table 1 with Table 2, we can see that the values of activation energy for microwave heated cooking decrease by approximately one-third time compared to the one for hot water dipped cooking.

Table 2 Calculated results of the parameters A, E, n and α for hot water dipped cooking

Shapes	A (s^{-1})	E(cal/mol)	$n(-)$	$\alpha(-)$	Literatures
slice	1.66×10^{15}	2.96×10^{4}	1.0	0.1	Kubota et al.[1]
sphere	2.10×10^{15}	2.94×10^{4}	1.0	0.1	Kubota et al.[2]
cube	1.25×10^{18}	3.46×10^{4}	1.0	—	Kasai et al.[6]

As the comparision of the values of $dx/d\theta$, the former's values are from two to three orders higher than the latter's values. It infers that the cooking mechanism for the former includes perhaps puffiness changes which affect the values of the cooking ratio by the rheological method, and the values of the former differ very much from those of the latter. The cooking of potato consisted both in physical changes such as the decomposition of the pectic structure and so on, and also in chemical changes such as the gelatinization of starch and so on. From this study, the cooking rate differ very much by the cooking method as well as by the measuring method of the cooking ratio.

In this study, the values of temperature for samples were not accurate, because the thermolables were set on the surface of samples. It seems that the observed values of temperature are smaller than the ones on the inside of the samples. If we could obtain more accurate values of the sample temperature, we should obtain better rate equations related to the heat transfer and the heat generation in internal samples.

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SUMMARY

In previous papers[1,2], we have studied the cooking-rate equations by the hot water dipped cooking of sliced and spherical potatoes. In this paper, we studied the cooking-rate equations by microwave heated cooking of potato slices. The values of the parameters in the rate equations by the temperature unsteady-state system were calculated by using a non-linear least square method[3].

The cooking-rate equations were obtained as follows:

$$dx/d\theta = k\,(1-x)$$
$$k = 5.09 \times 10^4 \exp\,[-9.90 \times 10^3/R_g(t+273.2)]$$

or

$$dx/d\theta = k\,(1-x)^{2.0}\,(x+5.37)$$
$$k = 7.78 \times 10^{12} \exp\,[-2.42 \times 10^4/R_g(t+273.2)]$$

where, $x(-)$: cooking ratio, θ(s): cooking time, t(°C): cooking temperature, R_g=1.987 cal/mol·°K: gas constant. The calculated results show that the values of cooking rate for microwave heated cooking are very much higher than those for hot water dipped cooking.

NOTATIONS

A, E, k, n and α:
parameters in rate equations
m : iteration number (–)
N : number of data (–)
R_g : gas constant (cal/mol·°K)
T and t : cooking temperatures (°K) and (°C)
x : cooking ratio (–)
W : weight on the load cell (g)
θ : cooking time (s)
σ : standard deviation (–)
Subscripts;
o and e : initial and equilibrium states
obs and cal : observed and calculated values

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ジャガイモ薄片のマイクロ波加熱における クッキング速度式に関する研究

久保田清・荒木英稀・鈴木寛一・江坂宗春

前報[1,2]において，薄片および球状のジャガイモの熱湯中クッキングにおけるクッキング速度式の設定に関する研究を行ってきた。本報では，薄片ジャガイモのマイクロ波加熱クッキングにおけるクッキング速度式の設定に関する研究を行った。温度非定常系となる速度式におけるパラメータを，非線形最小二乗法[3]によって求めた。次に示すクッキング速度式が得られた。

$$dx / d\theta = k(1 - x)$$

$$k = 5.09 \times 10^{4} \exp[-9.80 \times 10^{3} / R_{g}(t + 273.2)]$$

または，

$$dx / d\theta = k(1 - x)^{2.0}(x + 5.37)$$

$$k = 7.78 \times 10^{12} \exp[-2.42 \times 10^{4} / R_{g}(t + 273.2)]$$

ここで，x〔－〕：クッキング率，θ〔s〕：クッキング時間，t〔℃〕：クッキング温度，R_{g}=1.987 cal／mol・°K：気体定数である。上式は，マイクロ波加熱クッキングの速度が，熱湯中のそれよりも大変に大きいという結果を示している。