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A Control System for Automization of Food Sterilizing Process

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A microcomputer based control system was constructed to save energy consumption in the thermal sterilizing process. The functional accuracy of system was evaluated through the analysis of the thermal diffusivities of the model solid food, Alaska pollack surimi.

The heat penetration curves obtained through the experiments were typical for solid foods. The practical thermal diffusivity calculated from heat penetration curve was a constant value at steady sterilizing temperature, and this was independent of the holding time. At different temperatures, the thermal diffusivity values did not show remarkable differences when compared with those predicted by some experimental equations cited from the literatures. The maximal difference was within the range of ± 10.0%.

Introduction

The main purpose of the thermal sterilization in the food industry is to destroy microorganisms and to inactivate enzymes(Leniger and Beverloo, 1975). The microbiological safety of thermally sterilized food can be estimated by the F_0-value(Stumbo, 1973), which is defined as the integrated lethality of food. This value can be obtained by various quite different combinations of time and temperature.

On the other hand, the thermal sterilization is one of the most energy consuming process in the food industry(Singh, 1977; Barreiro *et al.*, 1984; Bhowmik *et al.*, 1985; Lappo and Povey, 1986). Moreover some chemical reactions can take place during the thermal process - they can lead to quite different qualities of foods(Teixeira *et al.*, 1969-a; Saguy and Karel, 1979; Heiss and Eichner, 1984). The process should be, therefore, optimized in the consideration of the relation between the degree of energy consumption and other factors, such as microbiological safety, nutritive value(Teixeira *et al.*, 1969-b), and sensory quality of the product.

For this reason, authors tried to develop a microcomputer based control system for automization of the steam sterilizing process as the first step of optimized thermal process research. The functional accuracy of the system was estimated by the comparison of the practical thermal diffusivities with those predicted by some experimental equations suggested in the literatures(Riedel, 1969; Han *et al.*, 1988; Lee, 1992).

Materials and Methods

Instrumentation

1. Retort

A detailed description of the automation system was shown in Fig. 1. The whole process was controlled by an IBM PC compatible AT 16-bits microcomputer(80286 CPU). A vertical type autoclave filled with appropriate amount of water was used as a steam sterilizing retort. The process was planned to operate in two steps, heating and cooling process. Heating medium was the saturated steam generated by an electric heater installed at the bottom of the autoclave. The cooling process was performed by spraying cooling water through four variable nozzles mounted on the lid of the autoclave.

Electrical amplifiers for thermosensors and for the operations of solenoid valves, cooling water pump, and electric heater were assembled with several IC modules. Interfaces between the CPU and amplifier were constructed by using A-D/D-A converters (PCL-812). The air exhaust at 100℃, retort pressure, and the spraying or discharging of the cooling water were controlled by the automatic operation of the solenoid valves. The operations of the electric heater, cooling water pump, and the solenoid valves were controlled by PWM(Pulse Width Modulation) control method, the SSR(Solid State Relay) device, and by the output of ON-OFF signal from the CPU.

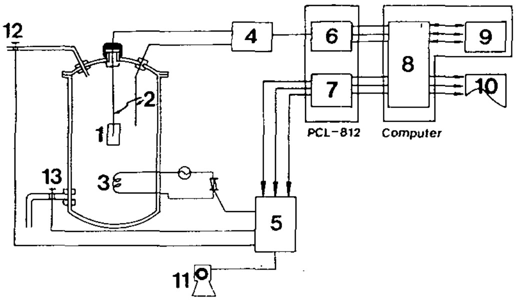


Fig. 1. Schematic diagram of retort automization system.
1: Sample, 2: Thermosensor, 3: Electric heater, 4, 5: Amplifier, 6: A/D conveter, 7: D/O interface, 8: Microcomputer, 9: Floppy diskette, 10: Printer, 11: Cooling water pump, 12: Cooling water inlet, 13: Cooling water outlet.

2. Thermosensor

The thrmosensor was manufactured with the T-type copper-constantan thermocouples(ϕ: 0.2mm). The thermocouple was inserted into a stainless steel syringe(ϕ: 1.8mm) and the heat sensing junction was welded. The heat sensing nib of the thermosensor was brought in contact with the inner edge of a thermosensor holding tube(THT) which was made of a stainless steel tube(ϕ: 2.8mm). The outer edge of the THT was fixed at the cold point of the model can as shown in Fig. 2. For avoiding the errors caused by the conductive heat through the stainless steel, the connection parts of the thermosensor and THT on the can wall were partially constructed with polyacetal resin and coated with some insulating materials, such as insulating varnish and flexible silicon tube.

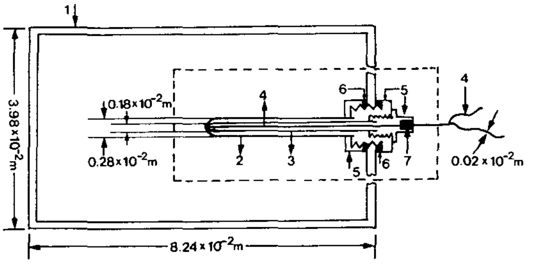


Fig. 2. Lateral view of thermosensor and model can.
1: Model can, 2: Thermosensor holding tube, 3: Thermocouple holder, 4: Thermocouple, 5: Polyacetal resin and flexible silicon tube, 6: Rubber packing, 7: Insulating varnish.

3. Amplifiers

The T-type copper-constantan thermocouple reveals potential differences of $1\sim5mV$ in the temperature range of 35~140℃, as shown in Fig. 3. To put such low-level potential differences in the CPU, the values had to be amplified to a corresponding input voltage ranges of A/D converter, $0\sim5V$ by using an operational amplifier module, as shown in Fig. 4.

The operations of the electric heater, the in- and

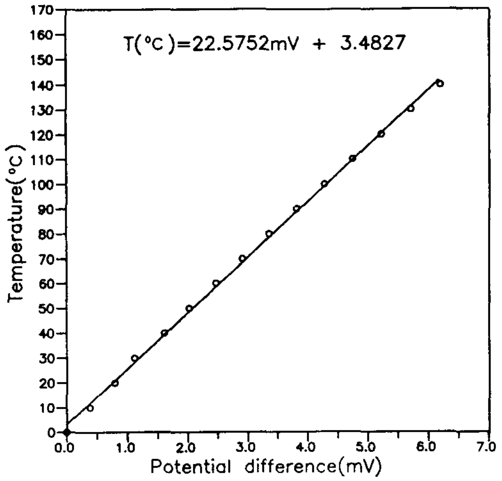


Fig. 3. Temperature vs. potential difference of thermosensor.

outlet valves for cooling water, and the cooling water pump were controlled by the ON-OFF signal of 4.5~5.0V, which was generated from the Digital Output(D/O) interface board.

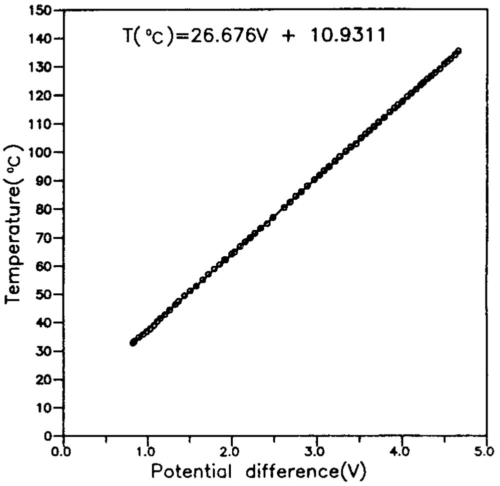


Fig. 4. Temperature vs. amplified voltage.

Control Program

1. Epitome of the control system

All the controlling and measuring devices installed on the retort were connected to the CPU, as shown in Fig. 5. The whole system was controlled by a program that was developed in Turbo C-language. The flow charts of the controller operating program and sub-routine programs for the whole system were shown in Fig. 6~Fig. 8.

2. Control of temperature

The temperature control program for the whole sterilizing process was composed of two steps. The first step program controlled the preheating temperature to shorten the come up time(CUT), and the second program controlled maintenance of the steady sterilizing temperature after CUT.

Fig. 9-a shows the general temperature response generated from the electric heater, which is controlled by the ON-OFF signal. In this case, the response of the heater is generally very slow. To avoid such triangular wave response, the electric power was controlled by PWM control method, as shown in Fig. 9-b. For the experimental apparatus constructed in this study, the SSR device is suitable for the operation of the electric heater, because the length of the temperature response period, t offers no problem, even though the heater response is slow. For this reason, the electric power was controlled by the control of the ON-OFF time ratio in a constant period, t. The algorithm for the temperature control to maintain a constant value was shown in Fig. 10. The allowable temperature error caused by the PWM control was less than ± 1℃.

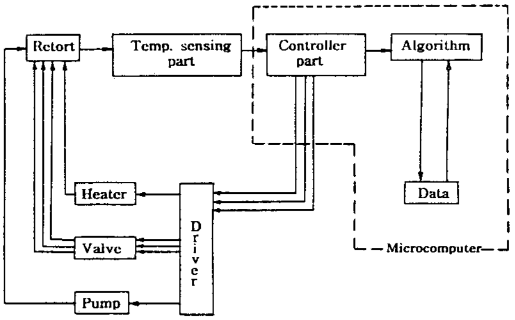


Fig. 5. Block diagram of computer based control system.

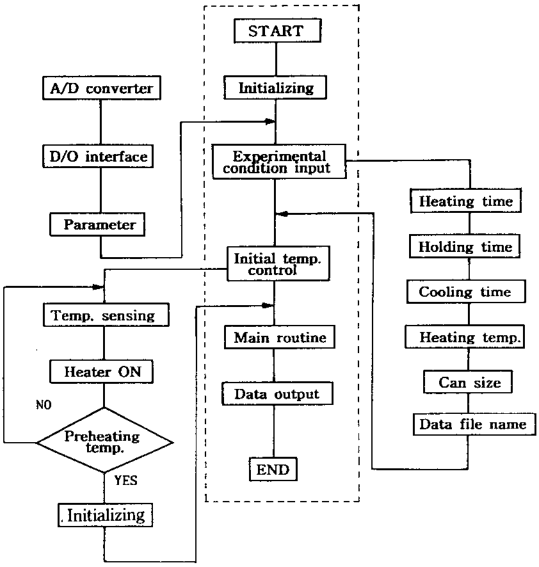
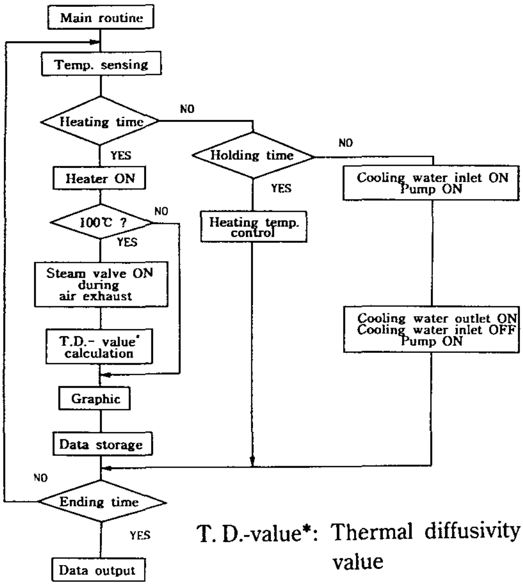


Fig. 6. Flow chart of controller operating program.

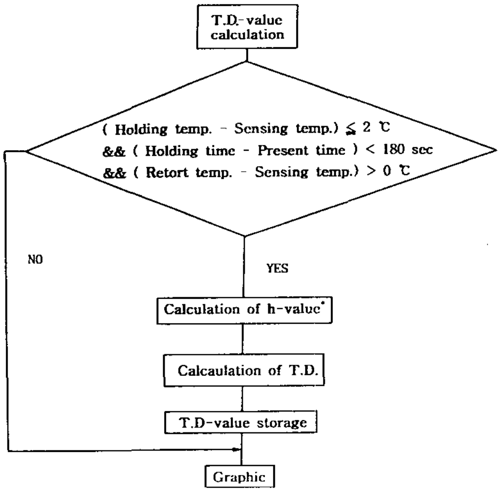
Model Foodstuff

Canned Alaska pollack surimi(APS, Alaska pollack meat paste) of known chemical composition, as shown in Table 1, was used as the model solid



T. D.-value*: Thermal diffusivity value

Fig. 7. Flow chart of sub-routine program.



$$\text{h-value}^{*}: \frac{\text{Holding temp.} - \text{Sensing temp.}}{\text{Holding temp.} - \text{Initial temp. of food}}$$

Fig. 8. Flow chart of sub-routine program for thermal diffusivity calculation.

Table 1. Composition of the APS (Unit: %)

Mositure	Crude protein	Crude lipid	Carbo-hydrate	Ash
74.2	22.8	0.5	1.0	1.5

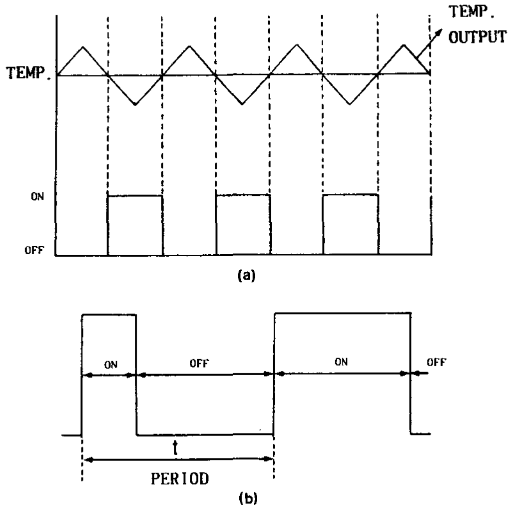
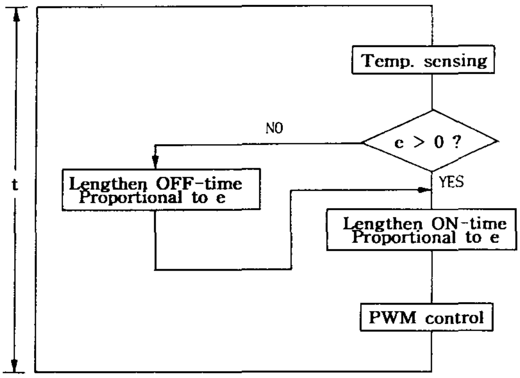


Fig. 9. Types of temperature response of the electric heater.



e= Temp H - Temp S

Fig. 10. Flow chart for retort temperature control program.
t: a period, Temp H: holding temperature, Temp s: sensing temperature

food. To avoid the thermal conductive error, the APS was well sealed in a cylindrical can(h=3.68cm and r=4.12cm) without head space.

Experiments

1. Operation of the system

After setting the can in the retort, all the operating conditions in Fig. 6 were put in the CPU through the keyboard, and then the system was automatically operated.

2. Analysis of heat penetration curves

According to the expression of Newman(1930), the relation between the time and temperature on the heat penetration curve of solid food can be expressed as a product of the solutions of the Fourier's second law. The solutions for plate and cylinder of infinite length, and sphere can be expressed as follows(Carslaw and Jaeger, 1959; Pflug *et al.*, 1965):

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{pl}=\frac{4}{\pi}\cdot\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{2n-1}\cdot\cos\left[\frac{2n-1}{2}\cdot\pi\cdot\frac{x}{\Delta x}\right]\cdot\exp\left[-\left(\frac{2n-1}{2}\right)^2\cdot\pi^2\cdot Fo_{pl}\right]\qquad(1)$$

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{cy}=2\cdot\sum_{n=1}^{\infty}\frac{J_0(B_n\cdot R/R_{max})}{B_n\cdot J_1(B_n)}\cdot\exp(-B_n^2\cdot Fo_{cy})\qquad(2)$$

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{sp}=\sum_{n=1}^{\infty}2\cdot(-1)^{n+1}\cdot\frac{\sin[n\cdot\pi(R/R_{max})]}{n\cdot\pi(R/R_{max})}\cdot\exp[-(n\cdot\pi)^2\cdot Fo_{sp}]\qquad(3)$$

where B_n is *n*-th root of the equation $J_0=0$. Fo_{cy}, Fo_{pl}, and Fo_{sp} are the Fourier numbers for infinite plate, cylinder, and sphere. The Fourier number is defined as$(\alpha\cdot t)/l^2$, where α and t are the thermal diffusivity and heating time, respectively, and l means Δx or R_{max}. J_0 and J_1 are Bessel functions of the first kind of order zero and one, respectively. R_{max} is the maximal radius, and R is the radial distance from midpoint. T_i and T_t are the temperatures of the APS at time t=0 and t=t, and T_R is the temperature of the heating medium. The values of x and Δx are the axial distance from midpoint and half-thickness of the plate of infinite length.

When the model container is a cylindrical can, the time-temperature relation on the heat penetration curve of the APS can be written as the following equation (4), which is the product of the equations (1) and (2).

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{can}=\frac{4}{\pi}\cdot\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{2n-1}\cdot\cos\left[\frac{2n-1}{2}\cdot\pi\cdot\frac{x}{\Delta x}\right]\cdot\exp\left[-\left(\frac{2n-1}{2}\right)^2\cdot\pi^2\cdot Fo_{pl}\right]\cdot2\cdot\sum_{n=1}^{\infty}\frac{J_0(B_n\cdot R/R_{max})}{B_n\cdot J_1(B_n)}\cdot\exp(-B_n^2\cdot Fo_{cy})\qquad(4)$$

At the cold point *i.e.* for R=0 and x=0 and $t\to\infty$ the equation (4) is simplified as the equation (5)

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{can}=\frac{4}{\pi}\cdot\exp\left[-\frac{\pi^2}{4}\cdot Fo_{pl}\right]\cdot2\cdot\frac{\exp(-B_1^2\cdot Fo_{cy})}{B_1\cdot J_1(B_1)}\qquad(5)$$

When the heating time, t in the Fourier number and the corresponding temperature of the product, T_t in the equation (5) are known, then the thermal diffusivity, α in Fourier number can be determined. Therefore, the accuracy of the system can be verified through the comparison of the measured practical thermal diffusivity of the APS with the thermal diffusivity predicted by some experimental equations(Riedel, 1969; Han *et al.*, 1988; Lee, 1992).

Results and Discussion

1. Heat penetration curves

All the heat penetration curves were plotted with the time interval of 0.2 seconds under the conditions listed in Table 2, and they were recognized as typical curves of solid food, as shown in Fig. 11.

Table 2. Conditions for the thermal sterilization of the canned APS

Sterilizing conditions	Heating temperature(℃)		
	105	110	115
Total process time(*min*)	120~152	120~130	120
Holding time(*min*)	105~137	105~115	105
Cooling time(*min*)	15	15	15

* Initial temperature of the APS was 12℃, and the air exhausting time at 100℃ was 90*s*.

2. Thermal diffusivities of the APS

The practical thermal diffusivities of the APS were calculated from the heat penetration curves in Fig. 11 and with the equation (5). The calculating conditions were as follows; Fo ≥ 0.2(Ramaswamy *et al.*, 1982), and just before the cooling process *i.e.* $(T_R-T_t)\leq 2$℃ and $(t_h-t)<180s$, here t and t_h were the time in the equation (5) and the holding time, respectively.

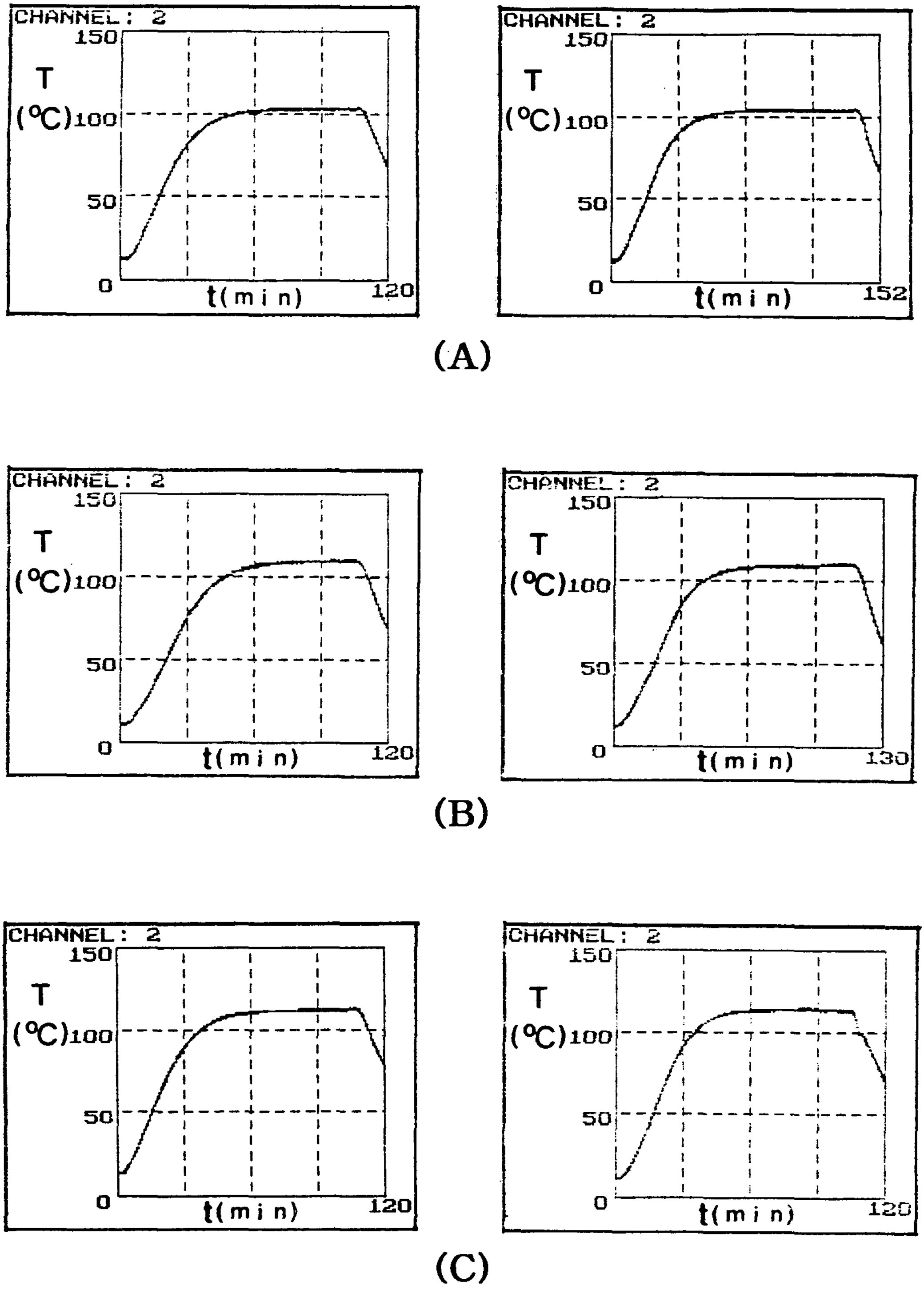


Fig. 11. Heat penetration curves of the APS at different temperatures.
(A) for 120~152 *min* at 105℃
(B) for 120~130 *min* at 110℃
(C) for 120 *min* at 115℃

The practical thermal diffusivities revealed no remarkable differences as compared with those predicted by the experimental equations such as (6), (7), and (8), which were suggested by Riedel (1969) for foods rich in moisture, by Han *et al.* (1988) for fish meat products, and by Lee(1992) for pork products containing fish meat.

$$\alpha = 0.0885 \cdot 10^{-6} + (\alpha_w - 0.0885 \cdot 10^{-6}) \cdot X_w, \ (m^2 \cdot s^{-1}) \tag{6}$$

$$\alpha = (1.096 + 0.5318 \cdot X_w) \cdot \alpha_w - 0.0057 \cdot 10^{-6} \cdot X_w - 0.0992 \cdot 10^{-6}, \ (m^2 \cdot s^{-1}) \tag{7}$$

$$\alpha = (1.885 + 0.52 \cdot X_w) \cdot \alpha_w - 0.0019 \cdot 10^{-6} \cdot X_w - 0.233 \cdot 10^{-6}, \ (m^2 \cdot s^{-1}) \tag{8}$$

Here X_w is the mass fraction of moisture. The values α and α_w are the thermal diffusivities of the APS and pure water at the heating temperature, respectively.

At different temperatures, the practically measured thermal diffusivities showed *ca.* ± 1.0~10.0% of differences as compared with those predicted, as shown in Table 3.

Table 3. Thermal diffusivities of the APS at different temperatures

Thermal diffusivities ($\cdot 10^{-6} m^2 \cdot s^{-1}$)	Heating temperature(℃)		
	105	110	115
Practical values	0.138~0.175	0.152~0.183	0.154~0.191
Mean of practical values	0.150	0.162	0.173
Values predicted			
by the eqn. (6)	0.146	0.149	0.150
by the eqn. (7)	0.146	0.148	0.149
by the eqn. (8)	0.152	0.154	0.157
Differences as compared			
with the eqn. (6)	2.7%	7.5%	9.0%
with the eqn. (7)	2.7%	7.5%	10.0%
with the eqn. (8)	-1.0%	4.5%	5.0%

* Initial temperature of the APS was 12℃, and the air exhausting time and the cooling time were 90*s* and 15*min*, respectively. The experiment was repeated 5 times at constant temperature.

Conclusion

A microcomputer based control system was developed for the automation of the steam sterilizing process of food. Accuracy of the system was evaluated through the analysis of the heat penetration curves and thermal diffusivities of the model solid food, Alaska pollack surimi. The heat penetration curves were recognized as the well-known typical curves of solid food. The practical thermal diffusivities showed no remarkable differences as compared with those predicted. The differences were in the range of ± 1.0~10.0%. From these results, it can be expected that the system developed in this study can be applied in the food industry without any great error.

Acknowledgement

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A Control System for Automization of Food Sterilizing Process

식품의 가열살균공정 자동화 시스템의 개발

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식품의 가열살균공정에 있어서 자동화는 에너지 소비의 성력화와 품질과의 관계 최적화를 위한 필수조건 중의 하나이다. 이를 위하여 마이크로컴퓨터를 이용한 자동화 시스템을 개발하였다. 시스템의 성능 및 정확도는 고형식품으로 사용한 명태 고기풀의 가열살균과정에서의 열침투곡선과 열확산도의 정확도로써 검토하였다.

자동화 시스템을 이용하여 측정한 명태 고기풀의 열침투곡선은 전형적인 고형식품의 열침투곡선을 나타내었다. 열침투곡선으로 부터 계산된 열확산도의 경우, 일정 살균온도에서는 다른 조건의 변화에 관계없이 일정한 값을 나타내었다. 가열살균온도를 변화시켜 구한 열확산도를 문헌상에 보고된 열확산도 추정식으로 구한 값과 비교하였을 때, 큰 차이를 보이지 않았으며 그 차이는 ± 10.0% 이내였다.