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Development of F_0-value Measuring System

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In order to establish the standard conditions for thermal sterilization of foods, a microcomputer based F_0-value measuring system was developed upon the basis of the time-temperature profile in food. F_0-value was calculated simultaneously from the time-temperature profile, and described as integrated lethality during the whole sterilization process. The accuracy of system was evaluated by the analysis of thermal diffusivity of the model solid food, Alaska pollack surimi.

The F_0-value could be measured precisely under the different sterilizing conditions as the varied time and temperature. The practical thermal diffusivities from various sterilizing conditions agreed well to the values predicted by some experimental equations suggested in the literatures. The differences were within the range of ±12%.

Introduction

It is well known that the main prupose of the thermal sterilization of food is to inactivate microorganisms and enzymes contained in food(Leniger and Beverloo, 1975). The microbiological safety of the thermally sterilized food can be estimated by the F_0-value(Stumbo, 1973). It is a criterion to guarantee the microbiological safety of commercially sterilized food that is sterilized at T℃ for F_T minutes, an equivalent sterilizing time of the F_0-value. It can be obtained by various quite different combinations of the heating time and temperature. On the other hand, the thermal sterilization is one of the most energy consuming process in food industry(Singh, 1977; Barreiro *et al.*, 1984; Bhowmik *et al.*, 1985; Lappo and Povey, 1986). Therefore, the process should be optimized in the consideration of the F_0-value, degree of energy consumption, and other quality factors of the product(Teixeira *et al.*, 1969; Saguy and Karel, 1979). For this reason, a microcomputer based control system for automization of the steam sterilizing process was developed in previous study(An *et al.*, 1993).

The F_0-value of food is also preferable to the process optimization. In spite of the great importance of the F_0-value, most of the food manufacturers in Korea have not any useful instrument for evaluating the thermal sterilizing process. Hence, authors tried to develop a system for F_0-value measuring instrument by the application of the results in the previous study(An *et al.*, 1993). The accuracy of the system was estimated by the comparison of the practical thermal diffusivities with those predicted by some experimental equations cited from the literatures(Riedel, 1969; Han *et al.*, 1988; Lee, 1992).

Materials and Methods

Retort

In the previous study(An *et al.*, 1993), the sterilizing process of food in a vertical autocalve was automated as the first step research for the process optimization. The same autoclave was used in this study, and the whole system was constructed as shown in Fig. 1.

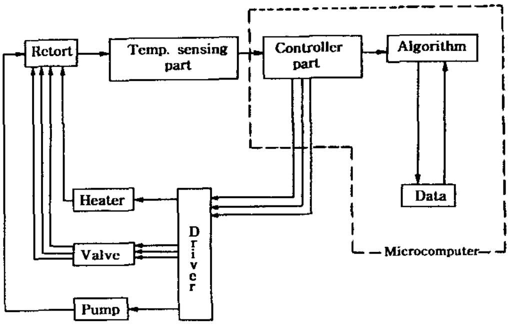


Fig. 1. Block diagram of computer based control system.

Model Foodstuff

The experiments were carried out with the canned Alaska pollack surimi(APS, Alaska pollack meat paste) of known chemical composition, as shown in Table 1. To avoid the thermal conductive errors, the APS was well sealed in a cylindrical can ($h=3.98cm$, $r=4.12cm$) without headspace.

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

Control program

The whole system was operated and controlled by a program, which was developed by using the Turbo C-language. After setting the model can in the retort, the system was operated in the order of the progress as in Fig. 2. In the previous study (An *et al.,* 1993), the thermal diffusivity was calculated from the time-temperature profile for evaluation of the accuracy of the automization system. In this study, the F_0-value was also calculated simulataneously with the thermal diffusivity from the same time-temperature profile by using the improved program. The corresponding sub-routine prorams were shown in Fig. 3~Fig. 5.

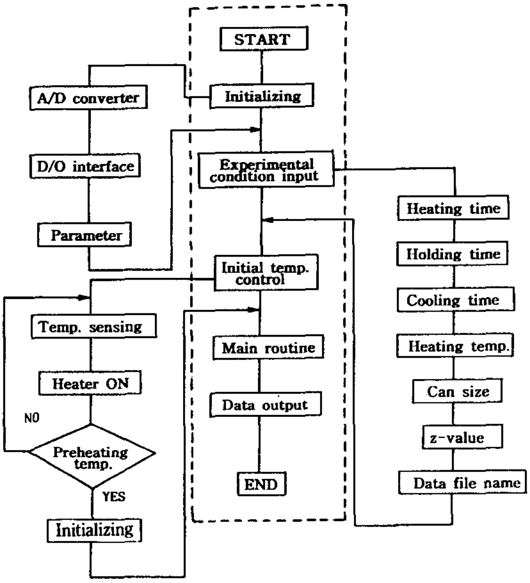
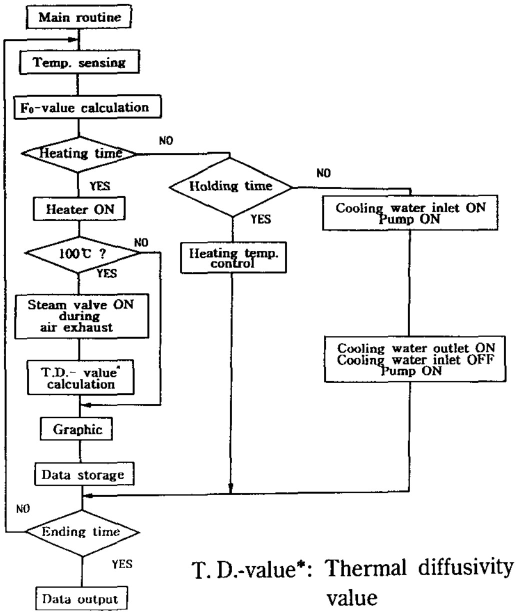


Fig. 2. Flow chart of controller operating program.

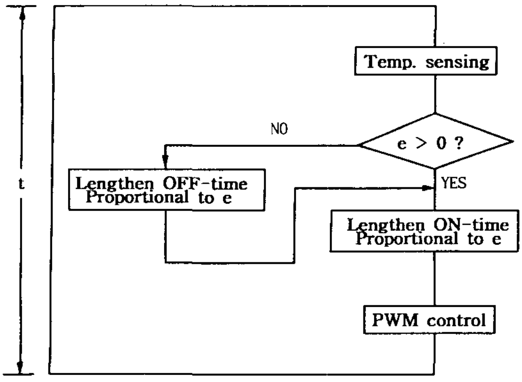


T. D.-value*: Thermal diffusivity value

Fig. 3. Flow chart of sub-routine program.

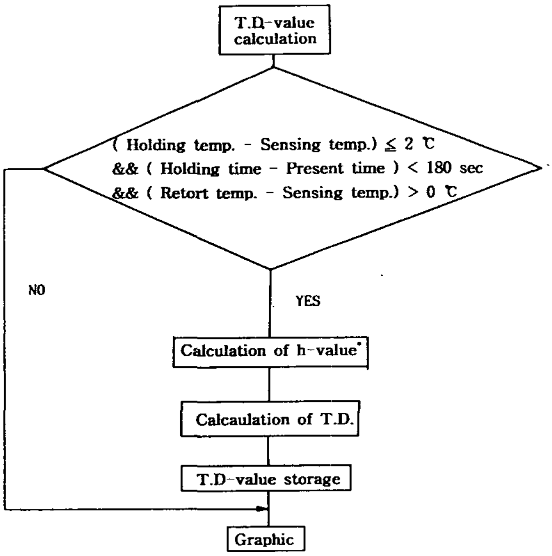
F_0-value Calculation

The F_0-value is the thermal processing time, which is required at 121.1℃ to reduce the population of bacterial spores with the D-value of $D_{121.1}$ and z-value of 10℃ to a desired reduction exponent, m.



e= Temp H - Temp S

Fig. 4. Flow chart for retort temperature control program.
t: a period, Temp H: holding temperature, Temp s: sensing temperature



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

Fig. 5. Flow chart of sub-routine program for thermal diffusivity calculation.

$$F_0 = m \cdot D_{121.1} = F_{T=121.1}^{z=10} \qquad (1)$$

And the lethal rate, L is defined as the ratio of the F_0 to F_T, which is the thermal processing time at T℃.

$$L = \frac{F_0}{F_T} = \frac{m \cdot D_{121.1}}{m \cdot D_T} = 10^{(T-121.1)/z} \qquad (2)$$

By definition, m is the logarithmic value of the ratio of initial population to surviving population of the bacterial spores and can be written as the equation (3), where D_T means the D-value at T℃ and defined as the equation(4).

$$m = \log(N_0/N_t) = \int_0^t D_T^{-1} \cdot dt \qquad (3)$$

$$D_T = D_{121.1} \cdot 10^{(121.1-T)/z} = D_{121.1} \cdot L^{-1} \qquad (4)$$

When the time and temperature are related by a continuous function, the equation (1) can be written as the equation (5).

$$F_0 = \int_0^t 10^{(T-121.1)/z} \cdot dt = \int_0^t L \cdot dt \qquad (5)$$

In a numerical analysis, it can be written as the equaiton (6).

$$F_0 = m \cdot D_{121.1} = \sum_0^t L \cdot \Delta t \qquad (6)$$

As we can see in the equation (5) or (6), the F_0-value becomes cumulatively greater with the elapsing heating time, t. Hence, the F_0-values can be calculated from the time-temperature profile during the whole heating and cooling process(Loncin, 1969; Takacs *et al.*, 1969-a and -b; Stumbo, 1973).

In the practical measurement, the momentary lethal rate of the model food was calculated, and the F_0-value was described as the integrated lethality during the whole sterilization process.

Results and Discussion

As shown in Table 2, the F_0-values of the APS at steady temperature became greater with the elapsing heating time. The corresponding heat penet-

Table 2. F_0-values(*min*) of the canned APS at 110℃

Holding time(*min*)	Total process time(*min*)			
	120	136	144	152
105	5.5896			
121		7.5632		
129			8.8454	
137				9.5744

* Initial temperature of the APS was 12℃. The air exhausting time at 100℃, and cooling time were 90*s* and 15*min*, respectively. The z-value was 10℃.

ration curves, which were plotted with the time interval of 0.2 seconds, were recognized as typical for solid food, as shown in Fig. 6.

The practical thermal diffusivities of the APS, which were plotted during the same heating time as in Table 3, showed greater values at higher temperatures. The corresponding heat penetration curves were also typical for the solid food, as shown in Fig. 7.

The time-temperature profile in the APS can be expressed as the product of the solutions of the Fourier's second law(Newman, 1930; Carslaw and Jaeger, 1959; Pflug *et al.*, 1965). In the case of the APS in a cylindrical can, it can be expressed as the equation (7) which is the product of the solutions for plate and cylinder of infinite length, as in previous study(An *et al.*, 1993).

$$\left(\frac{T_R-T_t}{T_R-T_i}\right)_{can}=\frac{4}{\pi}\cdot\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{2n-1}\cdot\cos\left[\frac{2n-1}{2}\cdot\pi\cdot\frac{x}{\Delta x}\right]\cdot\exp\left[-\left(\frac{2n-1}{2}\right)^2\cdot\pi^2\cdot Fo_{pl}\right]\cdot 2\cdot\sum_{n=1}^{\infty}\frac{J_0(B_n\cdot R/R_{max})}{B_n\cdot J_1(B_n)}\cdot\exp(-B_n^{\,2}\cdot Fo_{cy}) \quad (7)$$

Here B_n is n-th root of the equation $J_0=0$. Fo_{cy} and Fo_{pl} are the Fourier numbers for infinite cylinder and plate. J_0 and J_1 are the Bessel functions of the first kind of order zero and one, respectively. R_{max} and R are maximal radius and the radial distance from midpoint. T_i and T_t are the temperatures of the APS at time t=0 and t=t. T_R is the temperature of the heating medium. Δx and x are the axial distance from midpoint and half-thickness of the can.

To verify the accuracy of the F_0-value, the practical thermal diffusivities of the APS were compared with those predicted. The practical values were calculated from the heat penetration curves in Fig. 7 and with the equation (7). The calculating conditions were as follows; $n=1$, $x=0$, $R=0$, $Fo \geq 0.2$ (Ramaswamy *et al.*, 1982), $(T_R-T_t) \leq 2$℃ and $(t_h-t) < 180s$, where t and t_h were the time in the equation (7) and the holding time, respectively. The predicted values were calculated with the experimental equations of (8)~(10), which were suggested by Riedel(1969) for several foods rich in moisture, by Han *et al.*(1988) for fish meat products, and by Lee(1992) for pork products containing fish meat.

$$\alpha=0.0885\cdot 10^{-6}+(\alpha_w-0.0885\cdot 10^{-6})\cdot X_w,\ (m^2\cdot s^{-1}) \quad (8)$$

$$\alpha=(1.096+0.5318\cdot X_w)\cdot\alpha_w-0.0057\cdot 10^{-6}\cdot X_w-0.0992\cdot 10^{-6},\ (m^2\cdot s^{-1}) \quad (9)$$

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

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

Both of the thermal diffusivities showed no remarkable differences each other, and the difference was within the range of ±12%, as shown in Table 4.

Conclusions

In order to establish the criterion for thermal sterilization of food, a microcomputer based F_0-value measuring instrument was designed and manufactured upon the basis of the time-temperature profile in food under steam sterilizing process. The

Table 3. F_0-values of the canned APS under different heating temperatures

Conditions and F_0-values	Retort temperature(℃)			
	100	105	110	115
Total process time(*min*)	144	144	144	144
Holding time(*min*)	129	129	129	129
Cooling time(*min*)	15	15	15	15
F_0-value(*min*)	2.8459	5.2670	8.8467	13.9248

* Initial temperature of APS, z-value, and the air exhausting time at 100℃ were 12℃, 10℃ and 90*s*, respectively.

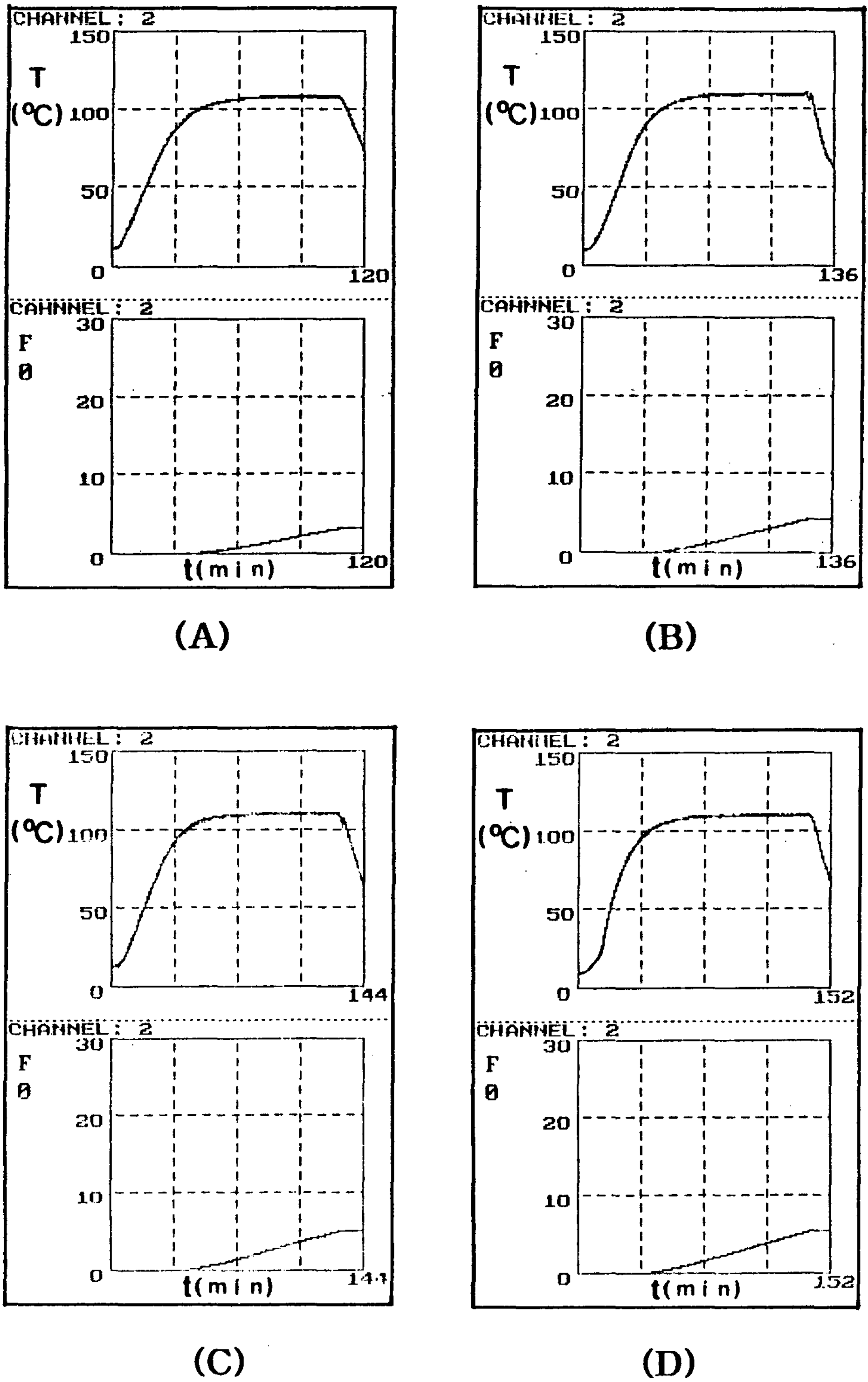
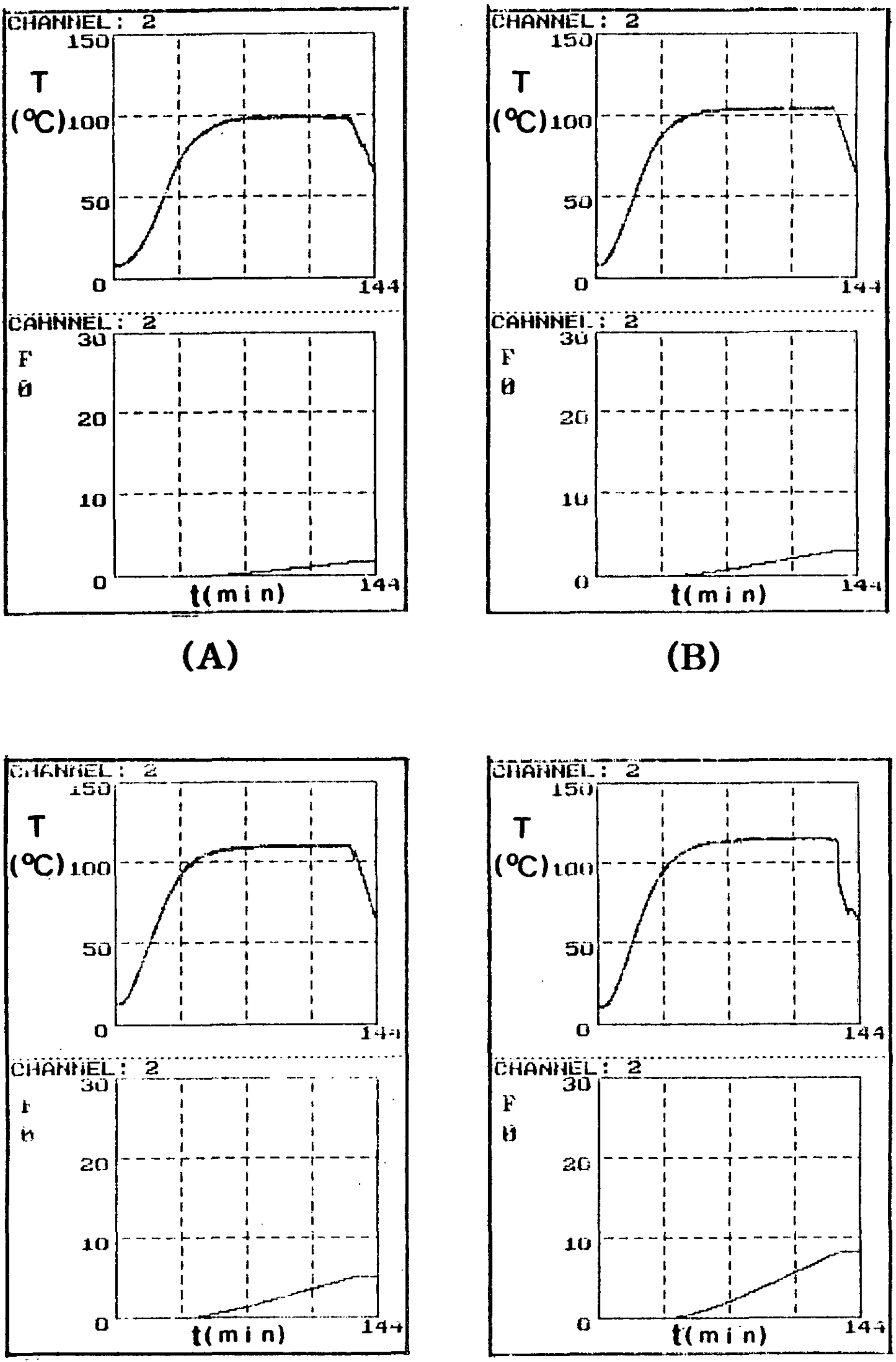


Fig. 6. Heat penetration curves of the APS at 110℃.
(A) for 120*min* (B) for 136*min*
(C) for 144*min* (D) for 152*min*



(A) (B)

(C) (D)

Fig. 7. Heat penetration curves of the APS at different temperatures for 144*min*.
(A) at 100℃ (B) at 105℃
(C) at 110℃ (D) at 115℃

Table 4. Comparison of the thermal diffusivities of the canned APS.

(Unit: · $10^{-6}m^2 \cdot s^{-1}$)

Temperature (℃)	Practical value (Mean value)	Values predicted by the equation		
		(8)	(9)	(10)
100	0.144~0.146 (0.144)	0.147 (-0.7~-2.0%)	0.146 (0.0~-1.4%)	0.150 (-2.7~-4.0%)
105	0.143~0.151 (0.147)	0.148 (-3.4~+2.0%)	0.148 (-3.4~+2.0%)	0.152 (-2.7~+0.7%)
110	0.143~0.159 (0.158)	0.148 (-3.4~+7.4%)	0.149 (-4.0~+6.7%)	0.158 (-9.5~+0.6%)
115	0.155~0.167 (0.161)	0.149 (+4.0~+12.0%)	0.151 (+2.6~+10.6%)	0.158 (-1.9~+5.7%)

* Initial temperature of the APS was 12℃. The air exhausting time at 100℃ and cooling time were 90*s* and 15*min*, respectively. The z-value was 10℃.
The experiment was repeated 5 times at constant temperature.

F_0-values were calculated from the time-temperature profiles in the model solid food, Alaska pollack surimi. The thermal diffusivities were also calculated from the same time-temperature profiles for the estimation of the accuracy of the instrument.

The practical thermal diffusivities revealed no remarkable differences as compared with those predicted. The maximal difference was within the range of ± 12%. The F_0-values could be measured precisely even to the minutest difference of the sterilizing conditions. From these results, it can be expected that the F_0-value measuring instrument developed in this study can be applied in the food industry without any great error.

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F_0－값 측정 시스템의 개발

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식품의 가열살균공정의 최적화는 에너지 소비의 성력화를 위한 공정 자동화와 제품의 미생물학적 안전성 및 영양적, 기호적 품질을 감안하여 이루어져야 한다. 본 연구에서는 이미 개발한 마이크로컴퓨터를 이용한 자동화 시스템을 개선하여 미생물학적 안전성 확보를 위한 가열살균기준 설정에 필수적인 F_0－값 측정 시스템을 개발하였다. F_0－값은 가열살균 중인 명태 고기풀의 냉점에서의 온도변화에 따라 순간치사율(lethal rate)을 구하고 전체 공정에서의 치사율의 합(integrated lethality)을 F_0－값으로 나타내었다. 또한 정확도는 냉점에서의 열침투곡선으로 부터 계산된 열확산도의 정확도로써 검토하였다.

F_0－값은 다양한 온도에서의 미세한 조건의 변화에도 불구하고 정확한 측정이 가능하였다. 또한 다양한 조건에서 동시에 계산된 명태 고기풀의 열확산도는 문헌상에 보고된 추정식으로 구한 열확산도와 큰 차이를 보이지 않았으며, 그 차이는 ±12% 이내였다.