IRRADIATION POWER EFFECT ON IR PASTEURIZATION BELOW LETHAL TEMPERATURE OF BACTERIA

ATSUSHI HASHIMOTO+, JUN SAWAI, HIDEO IGARASHI** AND MASARU SHIMIZU
Department of Chemical Engineering, Tokyo University of Agriculture & Technology, Tokyo 184

Key Words: Food Chemical Engineering, Food Process, Infrared Irradiation, Pasteurization, Radiative Heat Transfer, Irradiative Characteristic, *Escherichia coli, Staphylococcus aureus*

Introduction

Far-infrared (FIR) heaters made of fine ceramics are now manufactured. Applications of FIR can be expected to draw considerable interest in a broad field and in many important industries. In the food processing industry, the application of FIR to pasteurization for preventing processed foods from microbial contamination is desirable, and fundamental studies of such application are required. However, there have been only a few fundamental studies[1,3,4,5,10]

Previously, for *Escherichia coli* and *Staphylococcus aureus* suspended in phosphate-buffered saline (PBS, pH 7. 0)[5] and for the bacteria on an agar-plate as a wet-solid food model[3], the pasteurization effects of FIR irradiation were compared with those of conductive heating and of hot-air heating respectively. From these studies it was found that FIR irradiation was a more effective means of pasteurization than the conventional heating methods. Moreover, it was found that *E. coli* and *S. aureus* were injured and killed by FIR irradiation even below the lethal temperature[4].

However, the effect of the spectral distribution of irradiation power on FIR pasteurization has not been studied. This effect is a very important factor in FIR pasteurization, and the mechanism of FIR pasteurization may be made clear through a good grasp of the effect.

The present purpose is to make clear the interrelation between the pasteurization effect of IR irradiation and the spectral distribution of irradiation power. The pasteurization effect of FIR irradiation is compared with that of near-infrared (NIR) irradiation.

1. Experimental Apparatus and Methods

1.1 IR pasteurization

The pasteurization sample[4,5] and the irradiation chamber[3,4,5] were the same as those used in the previous studies. *E. coli* 745 and *S. aureus* 9779 were suspended in PBS (pH 7.0). A FIR heater (heater A) made of a mullite cylinder or a NIR heater (heater B) made of a quartz cylinder was used as the radiative heat source. Irradiation[4] and viable cell counts[4,5] were carried out according to the previous studies.

The suspension temperature was measured by CA-thermocouples sheathed by a stainless steel tube (0.25 mmϕ). The measurement method was the same as that used in the previous studies[4,5].

1.2 Measurement of irradiation power

Irradiation power was estimated experimentally by the methods used in the previous study[8]. The spectral distribution of radiative power emitted from heater A was estimated by using the surface temperature and the emissivity[5] of the heater, and that emitted from heater B was measured by a Fourier transform infrared spectrophotometer (JEOL, JIR-E500).

2. Experimental Results

2.1 Irradiation power

Figure 1 shows the spectral distribution at an irradiation power (q_{ir}) of 7.57×10^3 W.m^{-2} and the absorption coefficient of water ($\alpha_{W\lambda}$)[7]. Irradiation power emitted from heater A is mainly in the region where $\alpha_{W\lambda}$ is very high, whereas that emitted from heater B is mainly in the region where $\alpha_{W\lambda}$ is low.

2.2 Comparison of pasteurization effects

Pasteurization was performed under the same condition as that in the previous study[4]. The steady temperature of the bulk suspension was about 313 K, which is below the lethal temperature.

Figure 2 shows the effect of q_{ir} on the viable ratio (N_t/N_{t0}) of the test bacteria irradiated with heater A or B for 20 min.

N_t/N_{t0} of *E. coli* irradiated with heater A decreases slightly with increase in q_{ir}, and the decrease of that of *E. coli* irradiated with heater B is negligible. On the other hand, N_t/N_{t0} of *S. aureus* irradiated with heater A at $q_{ir} = 7.57 \times 10^3$ W.m^{-2} is 5.1×10^{-4}, though that of *S. aureus* irradiated with heater B is 4.8×10^{-1}.

Because the spectral distribution of irradiation power affects the penetration of radiative power into the

* Received December 25, 1992. Correspondence concerning this article should be addressed to A. Hashimoto.

+ A. Hashimoto is now with Department of Bioproduction & Machinery, Mie University, Tsu 514

**H. Igarashi is now with Department of Microbiology, Tokyo Metropolitan Research Laboratory of Public Health, Tokyo 169

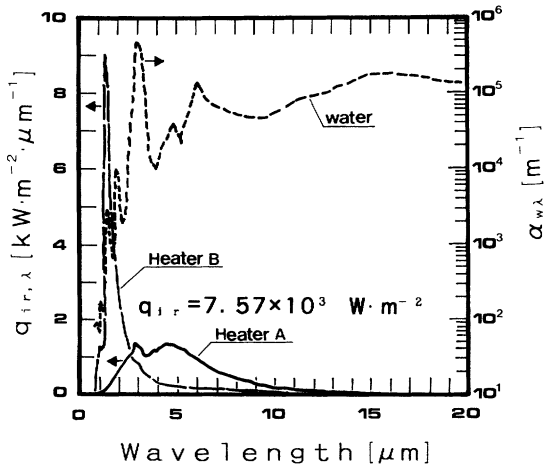

Fig. 1 Spectral distribution of irradiation power irradiating bacterial suspension and absorption coefficient of water

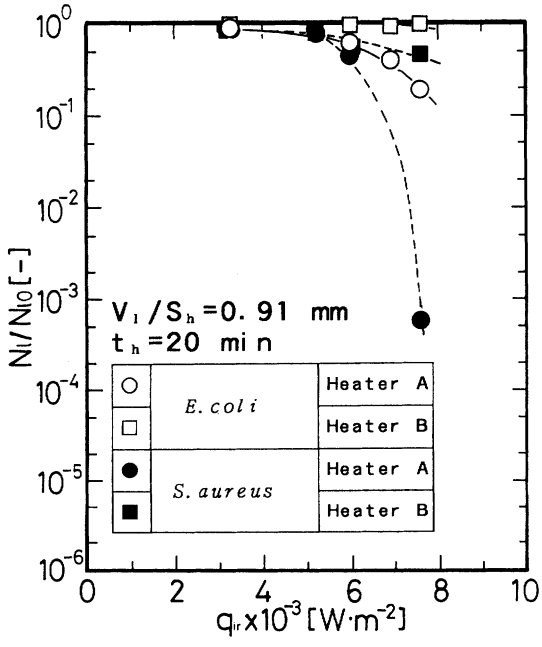

Fig. 2 Comparison of effect of q_{ir} on N_l/N_{l0}

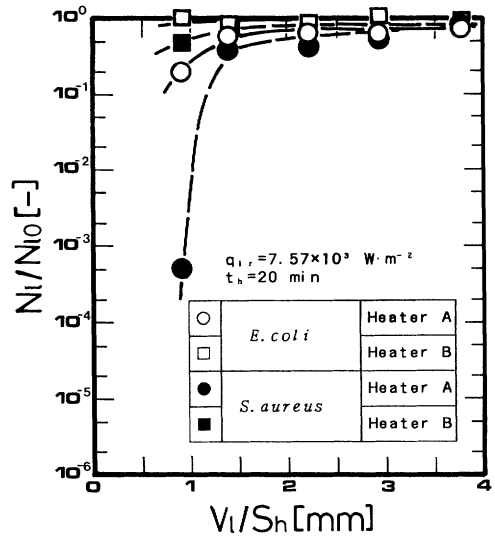

Fig. 3 Comparison of effect of suspension depth on N_l/N_{l0}

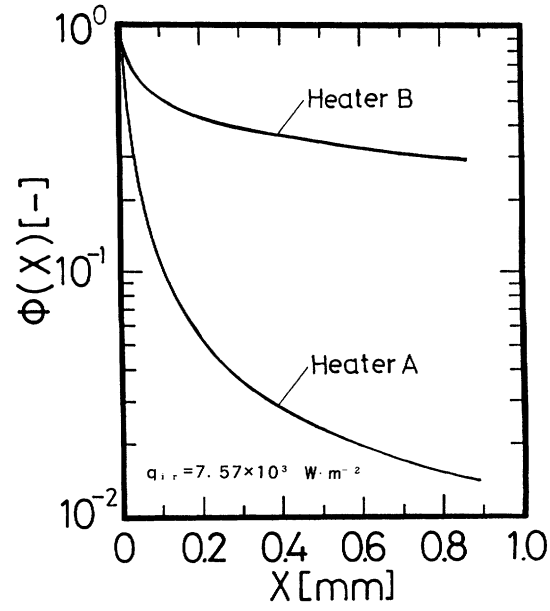

Fig. 4 Damping curves of irradiation power irradiating bacterial suspension

suspension, the effect of suspension depth on pasteurization was examined. **Figure 3** shows comparisons of the pasteurization effects between heaters A and B. The abscissa (V_l/S_h) is the ratio of the suspension volume to the area irradiated by IR, and is equivalent to the suspension depth.

For both *E. coli* and *S. aureus*, the differences of N_l/N_{l0} between heaters *A* and *B* is slight in the region of V_l/S_h thicker than about 1 mm. At $V_l/S_h = 0.91$ mm, N_l/N_{l0} of *E. coli* irradiated with heater *A* is 1.9×10^{-1}, though that of *E. coli* irradiated with heater *B* almost equals to that of the initial viable cell number. And N_l/N_{l0} of *S.* aureus irradiated with heater *A* is 5.1×10^{-4}, though that of *S. aureus* irradiated with heater B is 4.8×10^{-1}. Thus the advantage of FIR irradiation for pasteurization is remarkable for the test bacteria in a very thin suspension layer.

These experimental results indicate that FIR irradiation is more effective than NIR irradiation for pasteurization of bacteria suspended in PBS below the lethal temperature.

3. Discussion

By making use of the damping function, $\phi(x)$[6], given in Eq.(1), penetration of irradiation power into the suspension is estimated by using the concept described in the previous study[5].

$$\phi(x) = \frac{\int_0^\infty (1 - r_{w\lambda})\, q_{ir,\lambda} \exp(-a_{w\lambda} x)\, d\lambda}{\int_0^\infty (1 - r_{w\lambda})\, q_{ir,\lambda} d\lambda} \qquad (1)$$

It is assumed that the optical characteristics of the bacterial suspension are the same as those of water in the region of infrared radiation[2,7].

Figure 4 shows the calculated values of $\phi(x)$,

which is integrated numerically over wavelength from 0.78 μm to 20 μm, and x is the depth from the suspension surface. For heater A, 90% of the initial value of q_{ir} is absorbed within the suspension layer of 1.0×10^{-1} mm thickness. On the other hand, for heater B, only 43% of the initial value is absorbed within the suspension layer of that thickness.

From Fig.4, the temperature close to the surface of the suspension irradiated with heater A may be much higher than that with heater B. Thus it is thinkable that the test bacteria close to the surface of the suspension irradiated with heater A are stressed more seriously than the test bacteria irradiated with heater B.

The above suggests that the superiority of FIR pasteurization to NIR pasteurization is caused by the interrelation between the spectral distributions of the irradiation power emitted from heater A and the absorption coefficient of the bacterial suspension.

Concluding Remarks

It is found that FIR irradiation is more effective for pasteurization than NIR irradiation. The advantage of FIR irradiation is remarkable for pasteurization of test bacteria in a very thin suspension layer. The experimental results suggest that the superiority of FIR pasteurization to NIR pasteurization is caused by the very high absorption coefficient of the bacterial suspension in the FIR region.

Acknowledgment

The authors wish to thank Mr. Shuichi Muraishi of JEOL Ltd. for assisting in the measurement of the spectral distribution of irradiation power.

Nomenclature

N_l	= concentration of viable cells in bacterial suspension	[CFU.dm^{-3}]
q_{ir}	= irradiation power	[W.m^{-2}]
r	= reflectivity	[-]
S_h	= area of bacterial suspension irradiated by infrared radiation	[m^2]
t_h	= heating time	[s]
T_l	= temperature of bacterial suspension	[K]
V_l	= volume of bacterial suspension	[dm^3]
x	= depth of bacterial suspension layer	[m]
α	= absorption coefficient	[m^{-1}]
λ	= wavelength	[μm]
ϕ	= damping function defined by Eq. (1)	[-]

<Subscripts>

a	= air
b	= bulk
w	= water
λ	= monochromatic
0	= initial state

Literature cited

1) De Stoutz, P. and A. Queffelec: Proc. of the 11th Congress of International Union of Electroheat, Malaga, C3.5 (1988)
2) Hale, G. and M. Querry: *Appl. Opt.*, **12**, 555-563 (1973)
3) Hashimoto, A., H. Igarashi and M. Shimizu: *J. Chem. Eng. Japan*, **25**, 666-671 (1992)
4) Hashimoto, A., J. Sawai, H. Igarashi and M. Shimizu: *J. Chem. Eng. Japan*, **25**, 275-281 (1992)
5) Hashimoto, A., M. Shimizu and H. Igarashi: *Kagaku Kogaku Ronbunshu*, **17**, 627-633 (1991)
6) Hashimoto, A., M. Takahashi, T. Honda, M. Shimizu and A. Watanabe: *Nippon Shokuhin Kogyo Gakkaishi*, **37**, 887-893 (1990)
7) Hirota, K.: graduation thesis, Tokyo Univ. of Agr. & Tech. (1988)
8) Hirota, K., A. Hashimoto, T. Honda, M. Shimizu and A. Watanabe: *Nippon Shokuhin Kogyo Gakkaishi*, **38**, 136-143 (1991)
9) Morichi, T.: *Shokuhin Eisei Gakkaishi*, **13**, 173-183 (1972)
10) Van Zuillichem, D.J., K.Van't Riet and W. Stolp: "FOOD ENGINEERING AND PROCESS APPLICATIONS", vol.1, Magver, M.E. and P. Jalen ed., p. 595-610, Elsevier Applied Science, New York (1986)

(Presented in part at the 24th Autumn Meeting of the Society of Chemical Engineers, Japan at Nagoya, October 1991.)