Improving canned food quality with variable retort temperature processes

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Although technological advances such as aseptic packaging and agitated retort processing have dramatically improved the quality and economy of many heat-treated foods, those canned foods in which heat transfer is dominated by conduction have not benefited substantially. Variable retort temperature (VRT) processing can provide a means of increasing product quality and the energy efficiency of the process by improving the uniformity of heat penetration within the product. Computer simulation and systematic optimization routines are essential for efficient VRT process development.

Canned foods have a long history and are likely to remain popular for the foreseeable future owing to their convenience, long shelf life and economy. Thermal sterilization of canned foods is such a mature technology that it might be supposed that there is little potential for further development but, in fact, the technology continues to evolve. Recent developments have been directed towards better energy utilization[1], more efficient production[2], automation[3], lighter, more convenient[4], more appealing packaging[5], and better organoleptic quality[6–8]. This review article will focus on a type of processing technology that is receiving increasing attention from thermal processing specialists, and which has potential to improve both the economy and quality of some canned foods. Known as variable retort temperature (VRT) processing, this technology is specifically applicable to conduction-heated foods in hermetically sealed containers.

Loss of food quality during heat sterilization

Optimum thermal sterilization of food always requires a compromise between the beneficial and destructive influences of heat on the food. On the positive side, heat destroys microbial pathogens, spoilage organisms and endogenous and introduced enzymes that would otherwise render the food inedible or unsafe. At the same time, concentrations of heat-labile vitamins, particularly thiamine, vitamin C and folate are reduced[9]. In many foods, organoleptic quality is reduced by the heat of the sterilization process. The texture of canned vegetables, pasta, fish and meats is often softer than desired; canned milk products may be too brown; the surface of canned meats and other solid-packed products may be darkened by contact with the inner surface of the hot can, etc. Although heat may also be required to inactivate deteriorative enzymes or to modify texture and flavour, typically less heat is required for these functions than for sterilization. Important exceptions do exist, however, particularly with regard to softening of texture, as will be discussed below. Of course excess heat also has economic implications; energy consumption is a significant component of food processing costs. Well-designed commercial thermal processes for canned foods utilize a retort temperature at which microbial destruction proceeds more rapidly than quality loss. Studies of the kinetics of the chemical reactions involved in quality loss, as well as bacterial thermal death, have usually indicated first-order reactions with respect to time[10]. Furthermore, thermal death rates of bacteria generally undergo greater acceleration with increased temperature than concurrent reactions that lead to quality loss. This fact explains the well-known quality advantages of high-temperature, short-time (HTST) and ultrahigh-temperature (UHT) processes.

Unfortunately, the HTST and UHT concepts are severely limited for solid foods. The outer portions of cans of solid foods receive much greater heat than the centres; moreover, surface overcook becomes much worse as temperature increases. This is illustrated in Table 1 for conventional, constant retort temperature (CRT) processes, in which the maximum process temperature is achieved as rapidly as possible in the retort and is then maintained until steam-off time. Each row in Table 1 describes a single retort process and the quality of canned food that would result from that process. A finite difference model of conduction heating in a can was used to generate temperature histories at selected locations within the can[11]. With knowledge of the temperature histories of locations within the can, and measured z and T_{ref} values (see Box 1 for definitions) for the relevant quality attributes, one may calculate corresponding 'cooks'; that is the time that the product point of interest would need to be held at the reference temperature to achieve cumulative thermal destruction equivalent to that seen in the processed product. The temperature history of the material in the can centre was used to calculate cold-spot lethality (F_0) according to Eqn 5 in Box 1. Thiamine retention was estimated from a volume-averaged temperature history combined with reported values of z and $D_{121.1°\mathrm{C}}$ for thiamine destruction (Eqn 4 of Box 1)[12]. Surface cook ($F_{T\mathrm{ref}=100°\mathrm{C},\ z=23°\mathrm{C}}$) was calculated by converting the temperature history of the food surface to equivalent time at 100°C for an attribute with destruction kinetics matching those of a retorted fish product, as reported by Ohlsson[13], using Eqns 3 and 4 in Box 1. Note that although the process time required to

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Table 1. Effects of retort temperature of constant retort temperature processes on canned food products and process quality[a]

T_{retort} (°C)	Lethality (F_0; min)[b]	Thiamine cook (min)[c]	Thiamine retention (%)	Food surface cook (min)[d]	Process time (min)
113	8.1	40.2	47.6	383	106
115	8.1	36.6	50.8	**379**	87
117	8.1	34.8	52.6	391	74
119	8.1	**34.1**	**53.2**	416	64
121	8.1	34.3	53.0	453	58
123	8.1	35.2	52.2	502	52
125	8.1	36.5	50.9	561	**48**

[a] Based on a computer model[11] of a can (307 × 115) of food with a thermal diffusivity of 1.49×10^{-7} m^2/s

[b] Each process, represented by a row, resulted in equivalent centre-point lethality

[c] Thiamine loss of the process, averaged over the volume of the container [represented as the corresponding cooking time at the reference temperature (T_{ref}) of 121.1°C that would give equivalent quality, given that each 26.4°C increase ($z = 26.4$°C) results in a 10-fold increase in the rate of thiamine destruction]

[d] Proportional to the quality loss of food in contact with the inner surface of the container during the process [represented as the corresponding cooking time at the reference temperature (T_{ref}) of 100°C that would give equivalent quality, given that each 23°C increase ($z = 23$°C) results in a 10-fold increase in the rate of surface quality destruction]

achieve $F_0 = 8.1$ min decreased steadily with increasing retort temperature, quality attributes first improved, reaching a level of minimum loss (indicated in boldface type in Table 1), then deteriorated further with higher retort temperatures. Quality optima occur at different retort temperatures for the two attributes. In fact, the optimal temperature for sterilization with minimum quality loss has been shown to be a function of the z of the quality attribute as well as the critical location of quality loss within the can[11,14].

Little can be done to reduce the amount of heat required to sterilize foods. Bacterial endospores cannot be entirely excluded from food production and they must be destroyed if ambient-temperature preservation of moist, hermetically packaged, low-acid foods is to be successful. In practice, the slowest heating location or 'cold spot' within each container must reach and remain at lethal temperatures for sufficient time to ensure adequate spore destruction. Improvements in heat processes can therefore come about by only two routes: higher rates of heat transfer to critical locations in the food, or more homogeneous heat distribution within the food. Both have been successfully exploited in heat processing of fluid foods. Aseptic processes for milk, fruit juices, purées, soups, sauces and stews utilize fast convective heat transfer in heat exchangers. The products are heated rapidly, held for the necessary lethal period, then rapidly cooled before being filled and sealed, in a sterile environment, into previously sterilized containers. In-container sterilization of fluid or semi-fluid foods can also be accelerated by so-called forced convection processes in which containers are agitated by axial rotation[15], end-over-end rotation[16,17], or other movement during the cook phase. As well as accelerating heat penetration to the cold spot, constant mixing within the can greatly reduces overcook of the food that is adjacent to the container surfaces.

Unfortunately, many of our most popular canned foods do not benefit from aseptic processes or agitated cooks because they are not sufficiently fluid to permit convective heat transfer, either in a heat exchanger or a can. Tuna, ham, salmon, pork and beans, corned beef and canned pumpkin, to name but a few foods, heat within the can largely or entirely by conduction. Thermal processes for these types of products have remained almost unchanged for 50 years or more, although the containers and the retorts may have changed greatly. Because the heating rate into the product cannot be substantially accelerated, many have concluded that little potential for improvement exists. Nonetheless, if a process can improve the uniformity of the heat process within the can, it may be possible to improve product quality, reduce energy consumption and even reduce process time: VRT processing provides a promising approach to this problem.

VRT for volume-average quality

Any retort process in which the environment temperature within the retort is modulated during the process, according to a predetermined temperature sequence, to alter the heating profile within the product may be described as a VRT process (Fig. 1). The terms 'time-variable' or 'variable-temperature' process have also been used and are equivalent. It should be noted that although the heating rate of the CRT can centre is greater early in the process, the overall heating rate may be greater in the VRT process, owing to a higher final retort temperature. The VRT approach was not seriously considered in the earlier days of canning research, in part no doubt because the processes were cumbersome and unreliable when retort operation was strictly manual. Also, as we will see, VRT processes are difficult to study without the aid of computer simulations of heat transfer.

Teixeira *et al.*[14] first published a model of heat transfer within a can, based on the numerical finite difference technique; the model was used to examine CRT processes. Even before the advent of fast personal computers, computer simulations based on numerical calculation methods had several very useful features for thermal processing authorities engaged in the study of canned foods. A properly prepared and verified model can be used to carry out experiments when access to a retort is restricted. Furthermore, such experiments are quick, cheap and exactly reproducible. Also, the numerical model allows calculation of the temperature history of any spot or series of spots within the canned food. Traditional CRT processes are based on measured temperature histories of one spot within the food, usually the geometric centre or cold spot. This approach is adequate for sterilization prediction but temperature measurements at other locations are required if average nutrient retention, or surface quality are also to be considered. The placement of multiple thermocouples within a can does not solve the problem because the high thermal conductivity of the thermocouples disturbs the heating pattern. Teixeira *et al.*[14] used a two-dimensional model of a finite cylinder to study the effects of different CRT retort temperatures on nutrient retention in conduction foods. They showed that the HTST principle was not generally applicable in such foods. In fact, the HTST principle applies only to thin fluid films. In canned foods, an optimum retort temperature exists for each container–food combination; one that balances the benefits of improved heat transfer to the centre against the quality cost of overcook of the outer surfaces. Teixeira's group also showed that the optimum temperature depended on the z or activation energy (E_a) of the quality attribute under consideration. Optimum CRT temperature increases as z decreases or as E_a increases. Since these pioneering studies were published, numerical models of heating in cans have become quite common in the food processing literature[18,19].

Box 1. Evaluation of thermal destruction rates

Two systems are used to evaluate the impact of temperature on the thermal destruction rates of food components: the D and z model, which is based on decimal reduction; and the Arrhenius model, which is based on natural log reduction. The systems are for practical purposes equivalent. The D and z system has the advantage of allowing the direct calculation of accumulated lethality (F_0) of complex temperature histories.

$$\log N_t = \log N_0 - (t_T/D_T) \tag{1}$$

$$z = \left(\frac{T_2 - T_1}{\log D_1 - \log D_2} \right) \tag{2}$$

$$L = 10^{(T - T_{\text{ref}})/z} \tag{3}$$

$$F_{T\text{ref},z} = \Sigma \mathrm{L} \Delta t_T \tag{4}$$

$$F_0 = F_{T\text{ref} = 121.1°\text{C},\ z = 10°\text{C}} \tag{5}$$

$$k = A\, e^{(-E_a/RT)} \tag{6)*}$$

$$k = \left(\frac{2.303}{D} \right) \tag{7}$$

$$E_a = \left(\frac{2.303 R T_{\text{ref}} T_x}{z} \right) \tag{8)*}$$

N_t = spore count, nutrient concentration, etc., at time t

N_0 = N at time 0

T = temperature

t_T = time interval at temperature T

D_T = decimal reduction time at temperature T; time required for a decimal change in N

z = decimal reduction temperature; temperature change required for a 10-fold change in D

L_T = lethal or destruction rate at temperature T

T_{ref} = reference temperature

$F_{T\text{ref},z}$ = time for equivalent thermal destruction at T_{ref} for an organism or quality attribute of temperature sensitivity z (e.g. F_0, thiamine cook, surface cook)

k = destruction rate constant

E_a = activation energy per unit concentration

R = ideal gas constant

A = frequency factor; a constant for each thermally sensitive attribute

T_x = a temperature z° less than T_{ref}

* Temperatures must be given in kelvins

It is no coincidence that authors from the same group later published the first VRT study[20]. Computer models are even more useful for studying VRT processes than conventional CRT processes. CRT processes for a particular product are defined by one retort temperature, the process time being derived from the desired lethality at the centre (F_0). F_0 is in turn calculated from the temperature history of the centre. For each combination of retort temperature, container and food material, only one process exists for each F_0. In essence, the only question is which retort temperature is best for a particular product. By contrast, in VRT processes, temperature is a function of time. The experimenter must choose from a theoretically infinite number of possible processes. Choosing the best alternative is a daunting task but one that can be manageable with the aid of an efficient simulation model.

This first published examination of VRT processes was quite restricted[20]. As an example, a finite difference model of pork purée in a 307 × 409 can processed to an F_0 of 20 min was utilized and a limited range of VRT processes were considered. Retort temperatures started at 107°C and rose to 129°C by various linear, exponential or step-ramp functions. For comparison, a typical constant retort temperature might be 121°C. The quality attribute chosen for improvement (referred to as the 'objective function' or the 'response function' in VRT papers) was, in this case, overall thiamine retention. Only a slight improvement, ~2% in the best case, was noted, leading the authors to suggest that VRT was not likely to be very useful. Perhaps partly because of this conclusion, VRT papers were not plentiful for some time following the publication of this first paper. Saguy and Karel[21] published a new optimization approach, based on a gradient method in functional space in which

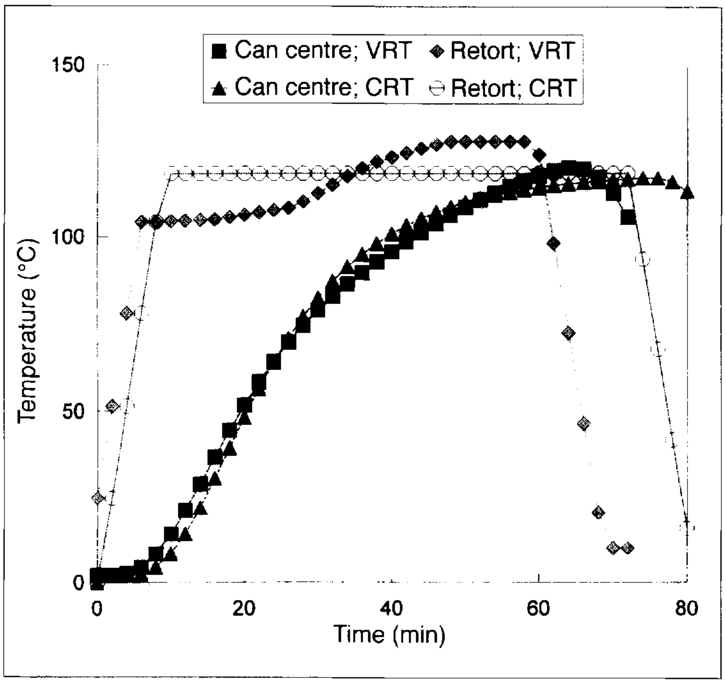

Fig. 1

Model retort temperature and can-centre temperature profiles of variable retort temperature (VRT) and constant retort temperature (CRT) processes for salmon in 0.5-lb cans[13]. The VRT process had a total centre-point lethality ($F_0 = 8.0$ min) equivalent to the CRT process but the process time was reduced by 16%.

each dimension was a variable of the VRT process[22]. They searched for a VRT process that, as in the study of Teixeira *et al.*[20], minimized thiamine loss. Again, a finite difference model was used to simulate heat penetration experiments. Quality was optimized according to the continuous minimum principle of control theory[23]. This search method was more thorough than the previous study and a process that yielded slightly better thiamine retention (2.3%) was found. Saguy and Karel[21] were the first to report that optimal VRT processes were very specific. They stated that each combination of container geometry, product and critical quality attribute would yield a unique VRT solution.

Nadkarni and Hatton[24] later applied a refined version of the same optimization technique, the 'distributed minimum principle control theory', to average nutrient retention in retorted cans and found no improvement with VRT. In fact, they concluded that VRT would always prove inferior to so-called bang-bang processes, that is constant maximum heating temperature followed by constant minimum cooling temperature. Although they were not far wrong within the limits of the problem as they defined it, later studies demonstrated that real benefits can be realized if quality attributes other than those that are averaged over the entire volume of the product are considered.

VRT for surface quality and process time savings

The first truly promising results of VRT computer studies were published in 1991[25]. Banga *et al.*[25], using a novel iterative procedure that was said to be computationally efficient to search for favourable VRT curve shapes, first examined optimum nutrient retention as in the earlier studies and confirmed the small advantage of VRT processes in this regard. They then went on to other objective functions, namely surface quality and processing time. This was a brilliant notion with real practical implications. In the canning industry, although one would not wish to promote a process that further decreased thiamine content, increasing its retention is not a priority, because thiamine retention does not have a major impact on consumer purchase decisions. In fairness to the pioneers of VRT processes, thiamine was chosen only as a model of quality loss, a model that was relatively easily measured and for which thermal kinetic parameters were available. Unfortunately, thiamine retention is not always the best quality model because it is distributed throughout the food and is not familiar to consumers. The surface appearance of food in a freshly opened can, on the other hand, is readily apparent to consumers. Banga *et al.*[25] showed that surface quality was improved up to 20% with the best VRT process.

If one applies the term 'quality' to everything that affects the value of the product, process time will be seen to be an important quality parameter. The retorting operation in canned food production is often the bottleneck of the entire plant, and hence process time is a determining factor in plant throughput. In addition, retort energy consumption is largely a function of process time. It must be remembered that processors have always had the option of reducing process time by going to a high CRT retort temperature. Generally, they have been constrained by the reduction in surface quality that would result (Table 1). Banga *et al.*[25] showed that VRT processes could yield surface quality and average lethality values equivalent to those of the best CRT process but with process times reduced by up to 16.5%.

Other studies have confirmed and augmented these results. Almonacid-Merino *et al.*[26] included a function in their finite difference model to simulate energy consumption. As well as being applicable to cost studies, energy consumption was used in their study to select VRT processes that did not require special steam removal or cooling devices. Previous studies did not place restrictions on the rate of change of temperature in the retort. In fact, some VRT profiles called for rates of cooling that were greater than could be achieved by passive processes and hence would require special steam removal systems. Such processes would be expensive to implement. This study indicated that VRT processes could increase plant production capacity by 20–50%, depending on the z of the critical surface quality parameter of the product in question. Another research group found greater reduction in retort times with VRT processes of low-profile, rectangular cans as compared with the cylindrical cans examined in other studies[27].

All of the studies described above have been based solely on computer simulations. None has described the application of these principles to actual retort operations. However, in a recent study, VRT processing was applied to a particular product, canned salmon, and confirmed with actual retort trials[11]. A new, rapid optimization search method was employed and VRT options were further constrained to meet practical commercial and regulatory requirements. VRT processes were shown to be capable of producing products of superior surface quality with equivalent F_0 values. Alternatively, equivalent quality could be produced with a process time (i.e. steam-on time minus come-up time) of 54 min as compared with 64 min for the CRT process (Fig. 1). It would appear that the way is now open to develop commercial VRT processes for specific products and to test these processes in commercial operation.

Search techniques for optimization

As mentioned above, each combination of food product and container geometry can be expected to require a different VRT process to yield the best quality and production rate. The definition of quality that a researcher employs will affect the shape of the optimum VRT heating and cooling curves. Furthermore, the choices are theoretically infinite. In practice, the upper limit of most conventional steam retorts for canned foods is 130°C or less. If we restrict the discussion to saturated steam retorts, the lower limit of retort temperature can be set at 104°C, as this is generally the minimum temperature of a properly vented retort chamber. Steam retorts must be vented to ensure that all air is flushed from the vessel with flowing steam because air has a much lower enthalpy than steam; thus, air will reduce the can heating rate. The duration of retort processes for cans with a capacity of ~0.5–1 lb is typically 30–120 min. Thus, the field of search must consider temperatures over a range of ~26°C and times ranging up to 120 min or more. Currently, it is not possible to generalize with confidence about the best shape of retort temperature profile for minimum process time, maximum surface quality, minimum energy consumption, etc. Several studies[11,25,27] have found temperature profiles with a general shape similar to that of the 'Retort–VRT' plot in Fig. 1 to be optimum, in which retort temperature is increased progressively throughout the heating phase. However, VRT processes in which retort temperature rises rapidly to a maximum early in the process, then gradually decreases during the remainder of the heating phase, before dropping rapidly in the cooling phase, have also been recommended[26].

Selection of a VRT process is a multi-factor optimization problem, and many techniques have been developed to deal with optimization problems[28–31]. In the case of VRT, the variable factors are the temperatures of the retort at different points in time during the heating and cooling phases of the process. Optimization theory is far from new but, until quite recently, has not been used much in food science. It has become more common as computer skills and computer optimization software have improved. Optimization techniques can be divided into two groups: computational optimization and evolutionary operation (EVOP) techniques. EVOP techniques were reviewed by Lowe[29] and one, simplex optimization, was further developed and popularized by Morgan and Deming[30]. Recent developments include several new EVOP techniques such as centroid mapping optimization[28], and random-centroid optimization[31]. Any of the EVOP techniques can be used together with a suitable computer model of heating to search for and test potentially beneficial VRT processes.

Conclusions

Ultimately, VRT processes selected with the aid of computer simulations and optimization routines need to be tested and verified with heat penetration studies of the actual canned product in a retort that is capable of reproducing VRT conditions. The most suitable units are retorts with computerized temperature programming, a feature that is becoming quite common in food retorts in any case. Once more VRT processes have been proven in full-scale cannery trials, we should expect to see a rapid spread of VRT processes to canneries throughout the world that process conduction-heated foods.

References

1 Bhowmik, S.R., Vichnevetsky, R. and Hayakawa, K. (1995) 'Mathematical Model to Estimate Steam Consumption in Vertical Still Retort for Thermal Processing of Canned Foods' in *Lebensm.-Wiss. Technol.* 18, 15–23

2 Scott, G.M. *et al.* (1994) 'Process Simulation Techniques for Batch and Continuous Thermal Processing Operations' in *Campden Food & Drink Research Technical Memorandum No. 710*, Campden Food & Drink Research Association, Chipping Campden, UK

3 Simpson, R., Almonacid-Merino, S.F. and Torres, J.A. (1993) 'Mathematical Models and Logic for Computer Control of Batch Process Operations: Conduction-heated Foods' in *J. Food Eng.* 20, 283–295

4 Patel, P.N., Chandarana, D.I. and Gavin, A. (1991) 'Internal Pressure Profile in Semi-rigid Food Packages During Thermal Processing in Steam/Air' in *J. Food Sci.* 56, 813–834

5 Silva, C.L.M., Oliveira, F.A.R. and Hendrickx, M. (1995) 'Quality Optimization of Conduction Heating Foods Sterilized in Different Packages' in *Int. J. Food Sci. Technol.* 29, 515–530

6 Abbatemarco, C. and Ramaswamy, H.S. (1995) 'Retention of Nutrients in Canned, Buffered Aqueous Solutions as Influenced by Rotational Sterilization in a Steam/Air Retort' in *Can. J. Agric. Eng.* 37, 345–350

7 Van Loey, A., Fransis, A., Hendrickx, M., Maesmans, G. and Tobback, P. (1995) 'Kinetics of Quality Changes of Green Peas and White Beans During Thermal Processing' in *J. Food Eng.* 24, 361–377

8 Price, R.B. and Bhowmik, S.R. (1994) 'Heat Transfer in Canned Foods Undergoing Agitation' in *J. Food Eng.* 23, 621–629

9 Lathrop, P.L. and Leung, H.K. (1980) 'Rates of Ascorbic Acid Degradation During Thermal Processing of Canned Peas' in *J. Food Sci.* 45, 152–153

10 Lund, D.B. (1982) 'Quantifying Reactions Influencing Quality of Foods: Texture, Flavor and Appearance' in *J. Food Process. Preserv.* 6, 133–153

11 Durance, T.D., Dou, J. and Mazza, J. (1996) 'Selection of Variable Retort Temperature Processes for Canned Salmon' in *J. Food Process. Eng.* 20, 65–76

12 Ramaswamy, H.S. and Ghazala, S. (1990) 'Centerpoint Nutrient Degradation in Heat Processed Conduction Heating Food Model' in *J. Food Process. Eng.* 12, 159–169

13 Ohlsson, T. (1980) 'Temperature Dependence of Sensory Quality Changes During Thermal Processing' in *J. Food Sci.* 45, 836–839

14 Teixeira, A.A., Dixon, J.R., Zahradnik, J.W. and Zinsmeister, G.E. (1969) 'Computer Optimization of Nutrient Retention in Thermal Processing of Conduction-heated Foods' in *Food Technol.* 23, 845–850

15 Berry, M.R. and Kohnhorst, A.L. (1985) 'Heating Characteristics of Homogeneous Milk-based Formulas in Cans Processed in an Agitating Retort' in *J. Food Sci.* 50, 209–214

16 Sablani, S.S. and Ramaswamy, H.S. (1995) 'Fluid-to-particle Heat Transfer Coefficients in Cans During End-over-end Processing' in *Lebensm.-Wiss. Technol.* 28, 56–61

17 Abbatemarco, C. and Ramaswamy, H.S. (1994) 'End-over-end processing of Canned Vegetables: Effect on Texture and Color' in *Food Res. Int.* 27, 327–334

18 Sandberg, G., Durance, T., Richard, P. and Leung, P. (1994) 'Thermal Processing Canned Meat with Sub-freezing Initial Temperatures: Thermal and Microbial Validation' in *J. Food Sci.* 59, 693–697

19 Bichier, J.G., Teixeira, A.A., Balaban, M.O. and Heyliger, T.L. (1995) 'Thermal Process Simulation of Canned Foods Under Mechanical Agitation' in *J. Food Process. Eng.* 18, 17–40

20 Teixeira, A.A., Zinmeister, G.E. and Zahradnik, J.W. (1975) 'Computer Simulation of Variable Retort Control and Container Geometry as a Possible Means of Improving Thiamine Retention in Thermally Processed Foods' in *J. Food Sci.* 40, 656–659

21 Saguy, I. and Karel, M. (1979) 'Optimal Retort Temperature Profile in Optimizing Thiamin Retention in Conduction-type Heating of Canned Foods' in *J. Food Sci.* 44, 1485–1490

22 Storey, C. and Rosenbrock, H.H. (1964) 'On the Computation of the Optimal Temperature Profile in a Tubular Reaction Vessel' in *Computing Methods in Optimization Problems* (Balakrishnan, A.V. and Neustadt, L.W., eds), p. 23, Academic Press

23 Pontryagin, L.S., Boltyanskii, V.G., Gamkrelidze, R.V. and Mishchenko, E.F. (1962) *The Mathematics of Optimal Processes* (English translation by Trirogoff, K.N.), Wiley-Interscience

24 Nadkarni, M.N. and Hatton, T.A. (1985) 'Optimal Nutrient Retention During the Thermal Processing of Conduction-heated Canned Foods: Application of the Distributed Minimum Principle' in *J. Food Sci.* 50, 1312–1321

25 Banga, J.R., Perez-Martin, R.I., Gallardo, J.M. and Casares, J.J. (1991) 'Optimization of the Thermal Processing of Conduction-heated Canned Foods: Study of Several Objective Functions' in *J. Food Eng.* 14, 25–51

26 Almonacid-Merino, S.F., Simpson, R. and Torres, J.A. (1993) 'Time–Variable Retort Temperature Profiles for Cylindrical Cans: Batch Process Time, Energy Consumption, and Quality Retention Model' in *J. Food Process. Eng.* 16, 271–287

27 Noronha, J., Hendrickx, M., Suys, J. and Tobback, P. (1993) 'Optimization of Surface Quality Retention During the Thermal Processing of Conduction Heated Foods Using Variable Temperature Retort Profiles' in *J. Food Process. Preserv.* 17, 75–91

28 Aishima, T. and Nakai, S. (1986) 'Centroid Mapping Optimization: A New Efficient Optimization for Food Research and Processing' in *J. Food Sci.* 51, 1297–1301

29 Lowe, C.W. (1964) 'Some Techniques of Evolutionary Operation' in *Trans. Inst. Chem. Eng.* 42, T334–T344

30 Morgan, S.L. and Deming, S.N. (1974) 'Simplex Optimization of Analytical Chemistry Methods' in *Anal. Chem.* 46, 1170–1181

31 Dou, J., Toma, S. and Nakai, S. (1993) 'Random-centroid Optimization for Food Formulation' in *Food Res. Int.* 26, 27–37

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