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SHERMAN LEONARD, RICHARD L. MERSON, GEORGE L. MARSH, GEORGE K. YORK, J.R. HEIL and T. WOLCOTT
Dept. of Food Science & Technology, University of California, Davis, CA 95616

FLAME STERILIZATION OF CANNED FOODS: AN OVERVIEW

INTRODUCTION

FLAME STERILIZATION is a method of commercially sterilizing canned foods by heating the cans in direct contact with a burner flame with rapid rotation to induce convection. It is recommended for liquid products and for particulate products packed in brine, syrup, or juice.

Flame sterilization was invented in France in 1957 (Cheftel and Beauvais, 1957; 1958a, b, c) and first described in the scientific literature in 1961 (Beauvais et al., 1961). Stériflamme (registered trademark of the Filper Corporation, San Ramon, Calif.) is the name given to the French-designed continuous sterilizer which makes use of the flame heating principle.

The attractive features of flame sterilization provide advantages for both the consumer and the food processor. The quality of Stériflamme products is markedly improved over that of products from conventional retorts (Kieseker, 1972; Klepetko and Longworth, 1972). The reason is that flame sterilization uses high temperatures to rapidly destroy microorganisms before extensive heat damage to the product can occur. The improvements are evident in better retention of the original vitamins, color, flavor and texture.

Other advantages of Stériflamme include simple installation and operation of the machines. Usually, construction of additional boiler capacity is not required. Although the process is continuous and high speed, there are no large pressure vessels and no inlet and outlet valves. Machines are designed for easy access for quick removal of dented or defective cans which cause serious jams in conventional continuous retorts. No discoloration occurs to cans or lithographed labels nor is there any damage to enamels or seaming compounds. Capital and operating costs are competitive with continuous steam retorts (Casimir, 1972a, b). The only limitation is that the can must act as its own pressure vessel. In certain products stronger ends might be needed on cans larger than 303 in diameter (Beauvais et al., 1961; Casimir, 1972a; Thomas, 1972).

Commercial Stériflamme units consist of four sections (Thomas, 1972): (1) a preheating section which employs atmospheric steam to bring the temperature of the contents of all the cans to a common temperature of 203 ± 1.8°F; (2) a heating section which employs a natural gas (or propane, or butane) flame directly on the can to bring the contents of the can quickly to a predetermined processing temperature, usually in the range of 248–266°F; (3) a holding section which uses a lower flame or intermittently spaced burners to maintain in-can temperature for the time needed for sterilization; and (4) a cooling section which utilizes water sprays to cool the cans to 95–104°F. In the French design, cans move continuously through the four sections, rolling on tracks which support the cans at the end seams. Processing time is controlled by chain-driven push bars which cause the cans to roll at a rate up to 100 cans per min per track, equivalent to an axial rotation of 20–40 rpm. Several tracks in parallel increase machine capacity without markedly altering machine dimensions.

In order to achieve more rapid heat transfer, some machines increase rotational speed with independently driven flat-top conveyors instead of stationary tracks. A machine variation developed in Australia (Hayward, 1963) increases the rate of heat transfer to the can by use of a reciprocating shuttle bar. The bar causes the cans to reverse direction periodically as they roll through the flame section on a track (Huntington and Casimir, 1972; Lewis and Lohning, 1972).

The first Stériflamme installations (1959 and 1960) were used to commercially sterilize canned peas (Beauvais et al., 1961). Since that time approximately 70 Stériflamme machines have been installed commercially. Nearly half of these are for canned mushrooms, seven of which are located in the United States. The other machines are commercially sterilizing vegetables in brine. In 1973, Filper Corporation installed a four lane machine at the Sun Garden Packing Co., San Jose, Calif. for the sterilization of whole peeled tomatoes in 303 × 406 cans.

Coincident with the expanding industrial use of Stériflamme there is a need for development of additional information to maximize the utilization of this process for specific products. We have undertaken such studies using a commercial-scale Stériflamme machine, pilot-scale cooker-coolers, and a process simulator which thermally treats a single can. In this first report we concentrate on the principles of HTST processing in connection with the mechanisms of flame sterilization.

EXPERIMENTAL

Stériflamme process

The methodology for Stériflamme processing of tomato juice and whole peeled tomatoes packed in juice was initially investigated in a single-can process simulator. This simulator (Fig. 1) consisted of a stain-

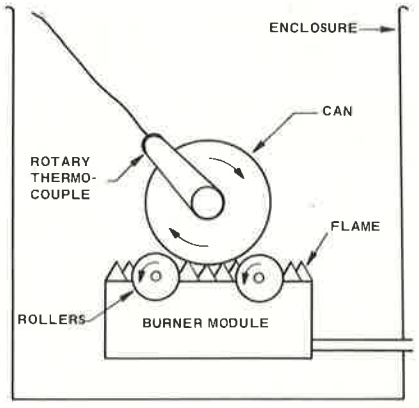

Fig. 1—Schematic end view of Stériflamme process simulator with burner module in place.

less steel, sheet metal box with interchangeable top and bottom modules necessary for steam preheating, flame heating and spray cooling. Inside the box two sets of rollers with variable drive rotated the can in place at any desired speed. Processing time in any section was controlled by changing the modules. The flame intensity was adjusted to a predetermined value for the heating or high flame period and lowered manually to simulate the holding or low flame section. The single-can simulator was capable of reproducing the time-temperature schedules achieved in the continuous pilot-scale and commercial Stériflamme machines which were used in the other phases of research.

Conventional process

Present-day commercial operation of rotary pressure cookers was simulated in a Steritort (Rotary Sterilizer, Canning Machinery Div., FMC Corp., San Jose, Calif.), operating at 215°F. Reel speed was maintained at 1.67 rpm which resulted in a can rotation of about 28 rpm for 303 × 406 cans at the bottom of the chamber.

Temperature measurement

In-can juice temperatures were continuously recorded by mounting Ecklund copper-constantan thermocouples (O.F. Ecklund, Cape Coral, Fla.) into the ends of cans. The point of measurement was 1 in. from the end on the longitudinal axis of the can.

Microbiological procedures

Bacteriological evaluation of processes was achieved by inoculating cans with spores of *Bacillus coagulans* ATCC No. 8038 cultivated on tomato juice nutrient agar. Standard plate counts before and after thermal processing were obtained by subculturing onto pour plates of dextrose-tryptone agar. The heat resistance (D value) of the spores in tomato juice at pH 4.1–4.2 was determined using the flask method (NCA, 1968a) at several temperatures.

RESULTS & DISCUSSION

Heat transfer with pressurized steam

Let us consider a can whose contents are perfectly mixed so that the temperature, T, is uniform throughout the liquid (except very near the wall). For heating in a steam environment, the accumulation of energy within the can is equal to the rate of heat input:

$$m \cdot C \cdot \frac{dT}{dt} = U \cdot A \cdot (T_r - T) \qquad (1)$$

(Rate of accumulation of energy in can) (Rate of heat transfer to can)

where m = mass of contents in the can, lb_m; C = heat capacity of can contents, $Btu/lb_m \cdot °F$; t = time of heating, hr; U = overall heat transfer coefficient from steam to can contents, $Btu/hr \cdot ft^2 \cdot °F$; A = area for heat transfer, ft^2; and T_r = retort temperature (temperature of steam), °F.

Integrating from the initial temperature T_i to temperature T at time t:

$$\int_{T_i}^{T} \frac{dT}{T_r - T} = \frac{U \cdot A}{m \cdot c} \int_0^t dt$$

yields the equation which forms the basis for the semilogarithmic plots used for heat penetration curves in the canning industry:

$$\log_{10} (T_r - T) = \log_{10} (T_r - T_i) - \left(\frac{U \cdot A}{2.303 \cdot m \cdot C}\right) \cdot t \qquad (2)$$

For steam heating, the area for heat transfer is the entire surface area of the can and T_r is known. The mass and heat capacity of the can contents are known, and U could be estimated, but usually the coefficient of time in Eq. (2) is determined experimentally as an f_h value from a plot of heat penetration data:

$$f_h = \frac{2.303 \cdot m \cdot C}{U \cdot A} \qquad (3)$$

Values of f_h are less than 20 min for rapid convection heating products in No. 2 cans (307 × 409) (Jackson, 1940) giving values of U of about 18 $Btu/hr \cdot ft^2 \cdot °F$, based on 20 oz fill weight, C = 1 $Btu/lb \cdot °F$ and an area of 68 sq in.

Heat transfer by flame heating

Calculation of flame heating rates is more difficult. The principle reasons for more rapid heat penetration with Stériflamme than with conventional steam heating are (1) the use of the high temperature flame and (2) the more rapid rotation of the can. Whereas steam retort temperatures are typically on the order of 212–280°F, the flame temperature varies between 2000 and 2500°F (Beauvais et al., 1961). This high temperature is applied periodically to the can wall as the can rotates through the flame. Heat is transferred to the can wall by radiation from the flame, by direct transmission at the point of contact of the flame and can, and by convection in the hot combustion gases which envelop the rotating can. Rapid rotation serves to increase the rate of heat distribution within the can by inducing convection currents in the liquid medium. This mixing is improved when particulate matter is present and when the fill weight is properly controlled to provide a headspace bubble which diverts fluid away from the can wall (Casimir, 1972c). In Stériflamme, the combination of flexible can ends and no external pressure allows the can to develop its own headspace even with completely filled cans.

Since the flame does not completely envelop the can as does the steam, and the flame temperature is not uniform, T_r in Eq. (1) is not precisely known and varies from point to point on the can. The surface area A is unknown and U, which now includes the effects of radiation and convection heat transfer to the can, is unknown and varies from point to point on the can surface. In spite of these difficulties we may use Eq. (1) with T_r set equal to an average flame temperature T_f. Furthermore, throughout the flame heating step, we can assume that the temperature driving force is constant, i.e.,

$$T_r - T \simeq T_f - T_i \qquad (4)$$

introducing about a 5% error at most. This is true because the can is heated by the flame only from 200°F, the temperature at the end of the steam section, to at most 275°F, the temperature at the end of the rising flame section. The latter temperature approaches the maximum temperature permitted by pressure limitations of the container. With this approximation Eq. (1) becomes

$$m \cdot C \cdot \frac{dT}{dt} = U \cdot A \cdot (T_f - T_i) \qquad (5)$$

which integrates to

$$T = T_i + \frac{U \cdot A}{m \cdot C} \cdot (T_f - T_i) \cdot t \qquad (6)$$

Thus it appears that a simple linear plot of temperature vs. time should adequately represent heat penetration data for the flame heating section. The exponential portion of the steam preheating step is still represented best by a semilog plot as indicated by Eq. (2).

Histories of the temperature of the covering juice during processing of whole peeled tomatoes in 303 × 406 cans are plotted in Figure 2 for both the Stériflamme and rotary pressure cooker processes. Segment (b — c) of the Stériflamme curve is linear whereas segment (f — g) of the Steritort curve illustrates the exponential approach to processing temperature in steam retorts. The data also illustrate the fast heating and cooling rates with Stériflamme and the much shorter processing time required to achieve the same degree of bacterial inactivation.

Bacterial inactivation and chemical degradation

The principal object of any thermal process is to reduce the

number of bacterial spores, n, in the can, from the original number, a, to a safe number, b. It is generally accepted (Stumbo, 1973) that when spores are held at a lethal temperature, they die logarithmically according to the expression

$$\frac{d(\log_{10} n)}{dt} = -\frac{1}{D} \qquad (7)$$

where t is time and D is a characteristic of the microorganism.

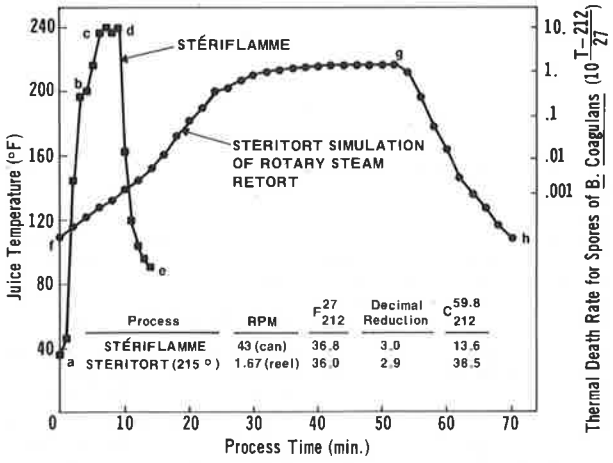

Fig. 2—Heat penetration curves during simulations of a Stériflamme process and a rotary pressure cooker process for whole peeled tomatoes in juice in 303 × 406 cans. The heating, holding and cooling cycles shown gave equal reductions in counts of spores of B. coagulans. a—b, steam preheating; b—c, heating flame; c—d, holding flame; d—e, cooling; f—g, steam heating; g—h, cooling.

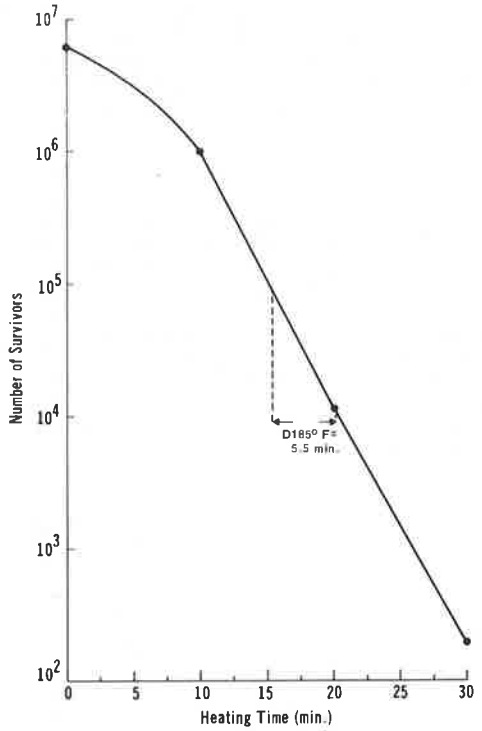

Fig. 3—Survivor curve for spores of B. coagulans heated in tomato juice at 185° F and pH 4.2.

An example of a survivor curve for spores of *B. coagulans* heated at 185°F is shown in Figure 3. The initial curve was caused by a heating lag; the D value is calculated from the straight portion of the curve.

The D value is in turn a logarithmic function of temperature T (Fig. 4). Empirically D may be expressed as:

$$D = D_{212} \cdot 10^{\left(\frac{212-T}{z}\right)} \qquad (8)$$

where D_{212} is the D value at 212°F and z is a constant, characteristic of the microorganism in question. From Figure 4, D_{212} = 0.52 min and z = 27°F for spores of *B. coagulans* in tomato juice.

Substituting Eq. (8) into Eq. (7) and integrating from time 0 to the end of the process, t_b, we may write

$$-\int_a^b d(\log_{10} n) = \frac{1}{D_{212}} \int_0^{t_b} \frac{dt}{10^{\left(\frac{212-T}{z}\right)}} \qquad (9)$$

or

$$D_{212}(\log_{10} a - \log_{10} b) = \int_0^{t_b} \frac{dt}{10^{\left(\frac{212-T}{z}\right)}} \qquad (10)$$

The left hand side of Eq. (10) is known as the F value of the process, or more specifically F^z_{212}, and may be calculated by evaluating the integral on the right hand side. In the general method (NCA, 1968b), the integration is performed graphically by plotting $1/10^{[(212-T)/z]}$ vs. t. The value $(\log_{10} a - \log_{10} b)$ is called the decimal reduction and can be determined experimentally with a test organism, as we have done with spores of *B. coagulans* in this study.

Similar reasoning can be applied to chemical changes which take place during the thermal process that can be treated as first order reactions, for example, the chemical reactions responsible for flavor, odor and textural changes. By analogy to Eq. (10) a "cooking value" or thermal degradation value can be defined as

$$C^{z'}_{212} = D'_{212}(\log_{10} a' - \log_{10} b') = \int_0^{t_{b'}} \frac{dt}{10^{\left(\frac{212-T}{z'}\right)}} \qquad (11)$$

where a′ = original concentration of a heat labile constituent

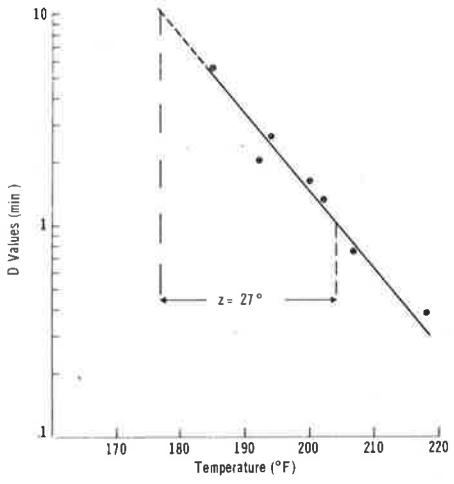

Fig. 4—Phantom death time curve for spores of B. coagulans in tomato juice.

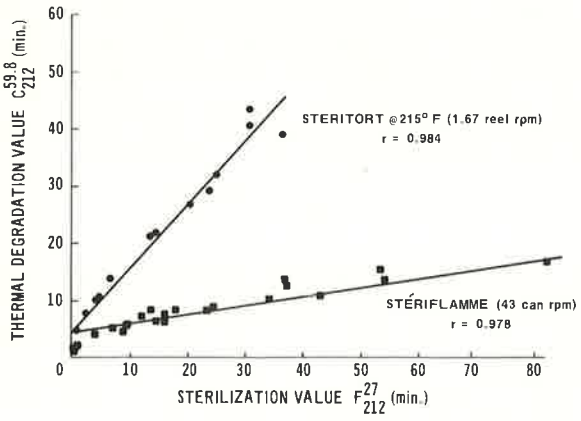

Fig. 5—Comparison of thermal degradation in a Steritort simulation of a rotary pressure cooker and a simulation of a Stériflamme process for whole peeled tomatoes in juice in 303 × 406 cans. r Values are regression coefficients.

such as a vitamin, color or enzyme; b′ = concentration at the end of the process, t_b′, in the same units as a′; D′ = D value for the chemical reaction; and z′ = z value for the reaction.

When the rate of the chemical change doubles with a 10°C (18°F) increase in temperature (Q_{10} = 2), z′ has a value of 59.8°F. This value is approximately valid for many chemical reactions affecting quality factors such as the heat destruction of thiamine in aqueous buffered solution (Feliciotti and Esselen, 1957) and in pork luncheon meat (Jackson et al., 1945), the conversion of chlorophyll to pheophytin (Schanderl et al., 1962), and the oxidation of ascorbic acid in orange juice (Evenden and Marsh, 1948). Thus standard thermal degradation values, $C_{212}^{z'}$, may be calculated from the right hand side of Eq. (11) similarly to the calculation of F_{212}^{z} values, but with z′ = 59.8°F.

It is the difference in z values between bacterial destruction and chemical degradation which provides the basis for improved product quality in any high temperature-short time process. For z values of 60°F, typical of thermal degradation, increasing the processing temperature from 212°F to 272°, for example, increases the rate of thermal degradation (which is proportional to $10^{[(T-212)/z]}$, Eq. (11) only by a factor of 10.But for a z value of 27, determined for spores of *B. coagulans,* the same 60°F increase in temperature results in a 167-fold increase in the rate of bacterial destruction.

A comparison of the amount of thermal degradation as related to sterilizing values in canned whole peeled tomatoes is given in Figure 5 for processes in both Stériflamme and a rotary pressure cooker. Values of $C_{212}^{59.8}$ and F_{212}^{27} were calculated from actual temperature data obtained in the juice (such as in Fig. 2) by numerical integration using Eq. (11) and (10), respectively. At a reasonable F_{212}^{27} value of 30, over four times as much chemical degradation occurred in the rotary pressure cooker as in the Stériflamme unit. These differences in thermal degradation would be even greater in low-acid foods when the important spoilage organisms have lower z values, or if the in-can temperature with Stériflamme were allowed to reach values higher than the 240°F used here. Differences between processes would be less if the steam retort were operated at higher temperature. The important point is that since high temperatures can be achieved more rapidly with Stériflamme, the canned foods may be adequately sterilized and cooled again before significant thermal degradation occurs.

The results presented here indicate the considerable potential of flame sterilization for shortening processing times and improving quality of canned foods. In the present paper we have confined our attention to exploring the in-container high temperature-short time processing principles which account for these results. However, there is a need for greater understanding of the heat transfer mechanisms involved in flame sterilization as well as more detailed study of the microbiological and chemical changes that occur during processing. In particular, as with any process which utilizes can rotation to increase the rate of heat transfer, thermocouple measurements are difficult and better methods of calculating thermal processes are needed. These aspects of Stériflamme processing will be discussed in future publications.

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