Reprinted from *Journal of Food Science*

HEATING CHARACTERISTICS OF CREAM-STYLE CORN PROCESSED IN A STERITORT: EFFECTS OF HEADSPACE, REEL SPEED AND CONSISTENCY

MAURICE R. BERRY, JR., ROBERT A. SAVAGE and IRVING J. PFLUG

ABSTRACT

The heat penetration factors (f_h and j) and sterilization value (F_o) for cans of cream-style corn heated in an FMC Steritort were determined from time-temperature data as a function of container headspace, reel speed, and product consistency. Four commercial instruments were used to measure product consistency. For commercially prepared cream-style corn in 303 × 406 cans, headspace (or fill weight) is the most critical of these parameters. Sterilization values that ranged from 39 to 78 min for 1/4 in. gross headspace were reduced to less than 1 min when the headspace bubble was eliminated. Positive headspacing devices or net-weight sensors are recommended for control of product lines. Other parameters that significantly influence the degree of agitation induced within the can are rotational speed of the cooker and product consistency. At low reel speeds or high product consistencies, sterilization values decrease dramatically.

INTRODUCTION

AS EARLY AS 1939, agitating cans of food during heating was shown to be effective as a means of increasing the rate of heat penetration (Adam and Stanworth, 1939). For viscous products such as cream-style corn (CSC), agitation induces convection within the can that allows short-time, high-temperature processing that improves appearance, flavor, and texture.

The Sterilmatic cooker (FMC Corp., Canning Machinery Div., San Jose, CA), recommended in 1949 for processing of CSC, is today the most widely used continuous agitating processing machine in the United States. Cans enter the retort and are indexed into a revolving reel; the cans move through the machine in a spiral pattern. Agitation is provided by allowing the cans to roll freely across the bottom of the retort.

The objective of this investigation was to determine the significance of the several critical parameters that affect the rate at which heat is transferred to cans of CSC heated in a Steritort (FMC Corp.) and, in turn, the sterilization value received by the product. The results of these studies using a Steritort would be applicable to commercial CSC processed in the FMC Sterilmatic processing machines.

MATERIALS & METHODS

Experimental plan

This study to determine the effect of headspace, product consistency, and Steritort rotational speed on the heating rate and lag factor of cream-style corn was carried out at the pilot plant facility of the Green Giant Company, Le Sueur, MN. The CSC was obtained from the production line of an adjacent CSC canning plant.

The cream for CSC was prepared from corn, starch, sugar, salt, and water. The cream and slit corn kernels were combined and passed through a DeZurik consistency controller (DeZurik Corp., Sartell, MN). The torque required to rotate a paddle in the CSC is measured and small amounts of hot water are added by the unit to maintain a constant torque, which is empirically related to product consistency. The product then flows directly to the filling machines.

Since commercial CSC varies within rather broad manufacturing limits, it was recognized at the onset of this project that we would be working with a variable product. It was decided that two sequential tests of six cans each would be carried out from each batch of CSC. The CSC for the duplicate test would be held under controlled temperature conditions while the first test was carried out. In this way each product test condition was evaluated twice.

Cream-style corn physical characteristics

CSC at or above 180°F was collected immediately before the filler bowl in the canning plant. Approximately 10 gal of corn was diverted into a 15-gal, stainless steel stock-pot.

In this report, we use the term "consistency" to describe the product characteristics. Consistency measurements were made on the product before heating and afterward on the fastest and slowest heating cans. Four commercial instruments were used to measure this quantity: the FMC consistometer (paddle A, C.W. Brabender Instr., Inc., South Hackensack, NJ), the Brookfield viscometer (Model HBT, Spindle 2, Brookfield Engineering Lab., Stoughton, MA), the Adams consistometer (Cefaly Experimental Co., Brentwood, MD), and the Stormer viscometer (A.H. Thomas Co., Philadelphia, PA).

Both the Brookfield viscometer and the FMC consistometer were used to measure total consistency. Each of these instruments measures the torque required to rotate a paddle in the product. The Adams consistometer measures the spread of a premeasured amount of CSC on a calibrated flat surface in 20 sec. The Stormer viscometer is used to measure the characteristics of the cream portion of the product. The CSC was strained through a No. 8 sieve, the cream portion was placed in a cup, and the time required for a constant amount of energy to be dissipated in rotating a cylinder in the cream was determined. The Stormer viscometer was used to monitor consistency in the plant, where product values were normally between 6.0 and 9.0 sec.

Washed, drained residue (WDR) is the percent of solids remaining on a No. 8 sieve after washing the product with water and draining. The WDR of the product in each test was measured. The WDR of the product from the plant varied from 25% to 40%.

In some cases, it was desired to evaluate a range of product conditions by modifying the product as obtained from the canning plant. Two techniques were used:

1. To vary the cream consistency and maintain the same WDR, extra cream was collected in the canning plant before the cream and slit corn kernels were mixed. The CSC sample was then split in the pilot plant and equal amounts of cream and water were added. The addition of about 1 qt of cream or water to 5 gal of CSC resulted in a difference of about 4 sec in the Stormer consistency readings.

2. To obtain a range of WDR's for the same cream consistency, a CSC sample was divided into two equal parts, and the kernels were strained from one part and added to the other.

Filling and sealing cans

The test cans were hand filled. Four filling conditions were used: fill weights of 480g, 488g, and 493g (all ± 0.2g) and full to overflowing (approx 510g). A fill of 488g in a 303 × 406 can results in a gross headspace of approximately 0.25 in. and was considered normal fill. After filling, the gross headspace was measured and then the cans were closed.

Heat penetration measurement

All heating tests were carried out using 303 × 406 cans. An Ecklund (Ecklund Custom Thermocouples, Cape Coral, FL) locking-type receptacle was located in the center of the manufacturer's end of the can. Ecklund CNS copper-constantan thermocouples,

—*Text continued on page 832*

Author Berry is with the Dept. of Health, Education & Welfare, Food & Drug Administration, Food Engineering Branch, Cincinnati, OH 45226. Author Savage, formerly with the Food & Drug Administration, is now with the USDA Food Safety & Quality Service, Washington, DC 20250. Author Pflug is with the Dept. of Food Science & Nutrition, University of Minnesota, Minneapolis, MN 55455.

2–3/16 in. long and 0.067 in. in diameter, were installed along the center line of the can at the geometric center.

An Ecklund thermocouple lead wire harness (rotary contactor) was used. The device included a slip ring unit that attached to the locking receptacle on the can and lead wire that connected to the thermocouple junction unit on the reel hub. The thermocouple lead wires were brought out of the Steritort through an external commutator unit at the end of the reel shaft.

The slip ring unit that attached to each can was inspected before and after each test to be sure that there was free movement between parts. The results of some heating tests had to be discarded either because drag developed in the slip ring unit or the slip rings stopped rotating altogether.

The temperature in six instrumented cans was measured during each heating test. Two thermocouples were located in the Steritort near the mercury-in-glass thermometer to obtain the heating medium temperature.

The thermocouple outputs, which were recorded using a strip-chart, temperature-recording potentiometer, were also measured, recorded, and punched on paper tape by a Doric Digitrend 220 data acquisition system (Doric Scientific Crop., San Diego, CA). Both systems were connected in parallel to all the thermocouples. Temperatures were measured at 30-sec intervals.

Steritort operation

Four Steritort reel rotational speeds were evaluated – 5.0, 6.5, 8.0 and 10.6 rpm. Normally, within each run at a given reel speed, two sets of three cans each had different product-container parameters. The difference was usually fill weight, since consistency and WDR varied routinely for the commercial product. But to better understand the effects of consistency and WDR, for some runs the commercial product was modified as previously described. A variation of these characteristics could thus be obtained within the same Steritort test.

The six thermocouple-equipped cans plus two additional cans for consistency testing were loaded into the Steritort. Thermocouple leads were connected, reel rotation was started, and the movement of cans was observed to be sure that all cans were rolling freely. The Steritort door was then closed and sealed.

The automatic temperature control was set for an operating temperature of 270°F, and the steam by-pass valve was opened. At time zero, the main steam valve was opened. The vents were closed at the end of 1 min of heating, and the by-pass valve was closed as the temperature approached 270°F.

The heating time (measured from steam-on to steam-off) was 22 min for tests at 5 rpm and 16 min for all other tests. At the end of the heating period, the steam valve was closed, and the 4-in. drain valve was opened along with the cooling water spray valve.

When cooling was completed (at a product temperature of about 100°F), the door was opened and the rotation of reel and cans observed to be sure that all cans were still rolling freely. The reel was then stopped.

Post-heating evaluation

The cans were removed from the Steritort and the vacuum measured to make certain the thermocouple packing glands had not leaked. The cans were opened and the headspace measured. The consistency of the CSC in the fastest and slowest heating cans was determined. The WDR of the CSC in two cans was also determined.

Data analysis

At the end of each day of testing, the heat penetration data on the punched paper tapes record was transferred to the University of Minnesota computer where, using appropriate software, sterilization values (F_o) were calculated by the general method and heating rate parameters (f_h, f_2 and j) were calculated. This rapid reduction of data produced results that were used to decide which subsequent tests were needed to best accomplish the objective in the limited time available.

Sterilization values were also calculated from manually determined heating rate parameters from the computer generated heat penetration graphs. The Ball method was used and lethalities were calculated using the actual initial temperature (T_o) for each can and an assumed initial temperature of 170°F.

RESULTS

Results for each of the variables evaluated (headspace, reel rotational speed, and product consistency) will be presented separately even though they interact.

Headspace

Agitation of the product in a can heated in a Steritort is facilitated by the presence and movement of the headspace bubble. The size of the bubble, the rotational speed of the can, and the consistency of the product together determine the rate of heat penetration.

Gross headspace before and after processing as a function of fill weight is shown in Figure 1. Both the mean (data symbols) and range (vertical lines) of headspaces at each fill weight are shown. The curves shown in Figure 1 represent linear regression analysis of the data. The two curves labeled "before processing" are for the first and duplicate tests made from a given sample of CSC. The difference in measured headspaces before processing for the two tests is probably due to deaeration of the CSC. The vapor was partially removed and the CSC cooled as it stood for about 45 min between tests. This effect was not significant for the after-processing data, and thus only one curve is shown. Headspace increased approximately 6/32 in. during processing. Gross headspaces before processing for cans with no headspace bubble are shown as 4/32 in. (the approximate counter-sink depth of the can). These cans were filled to overflow before sealing but headspaces were not actually measured. We believe that the variation in fill weight (496–512g) for the cans with no headspace is primarily due to variations in entrapped gases in the CSC.

In this study, we varied the fill weight of the cans to produce variations in headspace. The minimum sterilization value (calculated with T_o of 170°F) for nonmodified product for each fill weight for the various reel speeds is shown in Figure 2. The minimum F_o data shown are for cans with a high consistency; however, we have excluded the data from tests where we purposely changed the product (i.e., where WDR or consistency was modified). Changes in fill weight of as little as 5g were easily detected by the heat penetration data and subsequent sterilization value calculations. The most obvious effect is the significant reduction in sterilization value as the ingoing headspace bubble is reduced to zero.

The effect of fill weight on the heating rate parameter

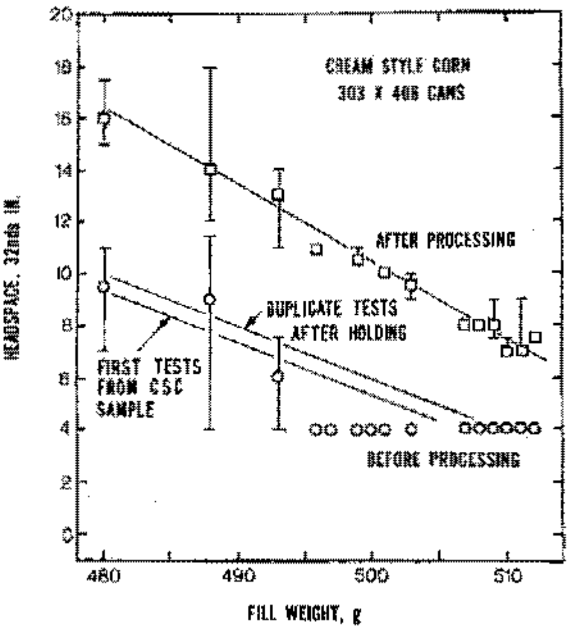

Fig. 1–Headspace correlation for cream-style corn in 303 X 406 cans.

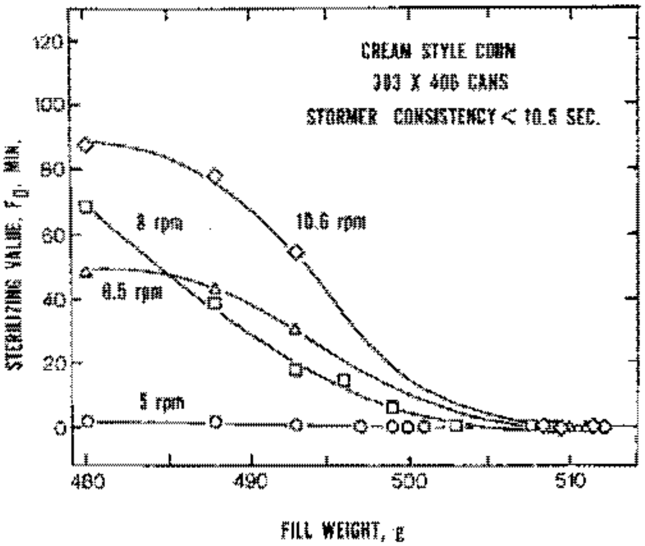

Fig. 2—Effect of fill weight on sterilization value.

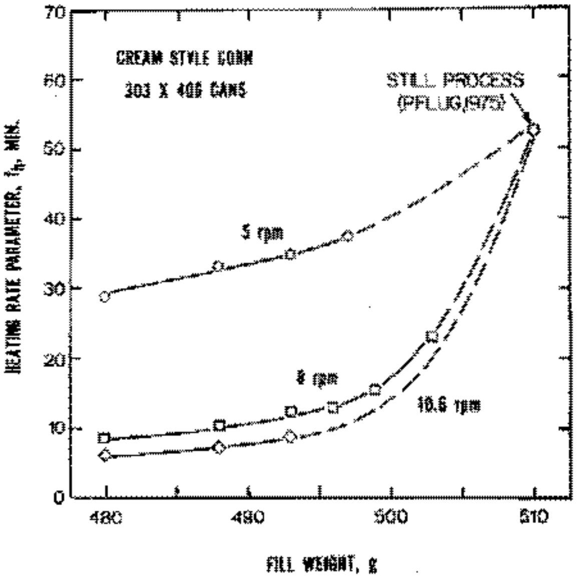

Fig. 3—Effect of fill weight on the heating rate parameter.

(f_h, or minutes required for the heat penetration curve to traverse one log cycle) is shown in Figure 3. The data represent the measured heating rate parameter for the slowest heating cans. No data are shown for the 6.5 rpm tests because broken-heating curves were obtained and a single value of the heating rate could not be computed. The heating rate parameter increases uniformly with increasing fill weight at all reel speeds. The data are shown approaching an f_h value typical of a still cook for CSC in 303 × 406 cans at the brimful condition (Pflug, 1975). Above about 500g, no data are shown since the process time was not long enough to fully develop the straight-line portion of the heating curve.

Reel speed

The influence of reel speed on the sterilization values and heating rate parameters as a function of fill weight and consistency are shown in Figures 2 and 3, and 4 and 5, respectively. The results indicate that the higher the reel speed, the more effective the agitation and the larger the sterilization value for the same process time. Although sterilization values were slightly larger at 8 rpm, there was little difference between the 6.5 and 8.0 rpm runs. The most interesting difference was the broken-heating phenomenon that consistently occurred at 6.5 rpm. After 4–8 min, the heating rate parameter increased by 50 100%. Straight-line heating occurred only with high consistencies or zero headspace.

Consistency

In Figure 6 are shown the FMC consistometer readings as a function of WDR. The FMC consistometer measures in Brabender units (B.U.), and the measure is influenced by the two components of CSC; cream and kernels. To show the role of the cream portion of the CSC, the data have been keyed to the relative Stormer readings: low/5.6–7.5, medium/7.5–9.0, and high/9.0–16.2 sec as represented by the different symbols.

Lines have been drawn approximating Stormer values of 7.5 and 9.0. In general, FMC B.U. values can be the result of thick cream and a low percentage of kernels, or thin cream and a high percentage of kernels. Either a Stormer consistency of 9.0 sec and a WDR of 26%, or a Stormer of 7.5 sec and a WDR of 34% have an FMC consistency of 70

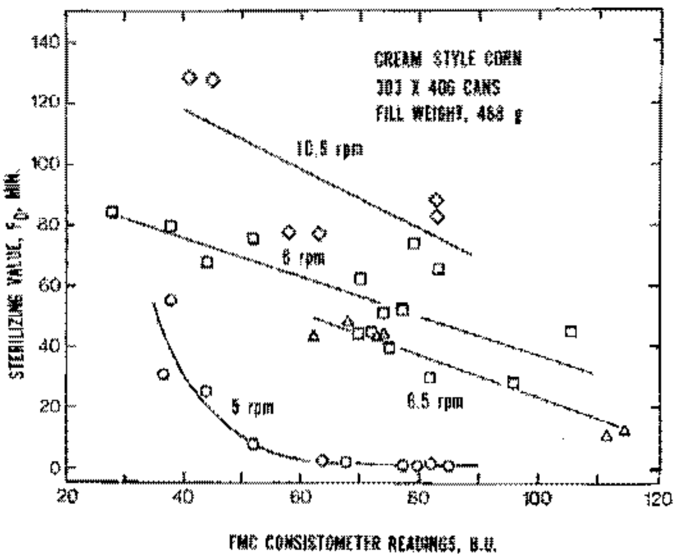

Fig. 4—Effect of consistency on sterilization value.

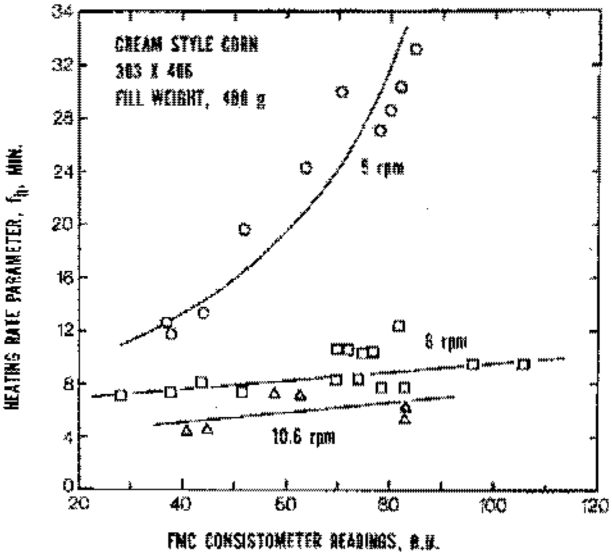

Fig. 5—Effect of consistency on the heating rate parameter.

B.U. (dashed lines, Fig. 6). A similar correlation was found for the Brookfield consistency data.

Consistency is a measure of a product's internal resistance to flow when subjected to an external stimulus. The higher the consistency, the thicker the product, or the more resistant it would be to movement such as agitation in a Sterilmatic cooker. For a product like CSC, consistency is influenced both by the thickness of the cream and the amount of particulate matter (WDR) in the mixture (Fig. 6). Consistency measurement is further complicated by the product temperature and rheological effects. Consistency comparisons must be made at the same temperature (normally 170 or 180°F for CSC), with the same viscometer. Even then the unknown rheological effects of holding and mixing may influence the results.

Control of product temperature for the consistency measurements was not possible. Some insight as to the effect of temperature on consistency can be obtained by comparisons of the same sample of corn at different temperatures. For most combinations of processing parameters, an initial run was followed immediately by a duplicate run. The average product temperature was 168°F for the ingoing FMC consistency measurements for the initial runs. For the duplicate runs, the temperature was 148°F. The combined result of the holding time and the decrease in product temperature was to increase the average FMC consistency from 70 to 81 B.U. Based on the close agreement between the sterilization values (corrected to an initial temperature of 170°F) in the first and second tests of each sample of CSC, we conclude that the difference in measured consistencies are primarily the result of the temperature differences and only to a much lesser extent to changes in rheological properties. If only a temperature effect is assumed, a correction factor of about −0.5 B.U./°F appears reasonable. For the Brookfield and Stormer viscometers, the factors are −25 centipoise/°F and −0.1 sec/°F, respectively.

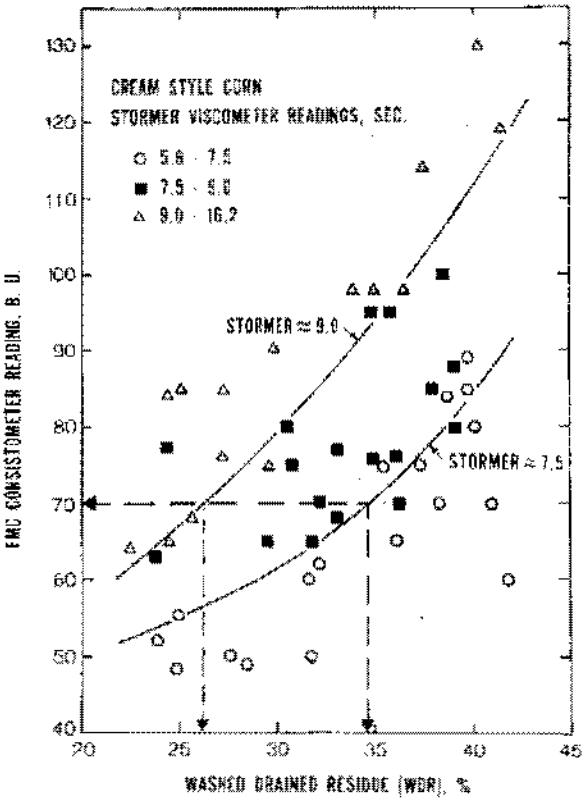

Fig. 6—Components of total consistency for cream-style corn.

Both the FMC consistometer and the Brookfield viscometer measure total consistency, whereas the Stormer viscometer characterizes the cream portion only. FMC and Brookfield consistencies were in agreement, probably because the two instruments are similar and both measurements were taken from one sample and at the same temperature. But the FMC consistometer was more sensitive to WDR, probably because of the difference in the shape of the shearing devices. The Brookfield spindle was T-shaped and made of small-diameter rods, whereas the FMC paddle was a flat, rectangular plate. For the same Brookfield consistency, CSC with higher WDR yielded higher FMC consistencies.

The effect of product consistency on the sterilization value is shown in Figure 4 at reel speeds of 5, 6.5, 8, and 10.6 rpm. Data points shown are for a fill weight of 488g and represent the slowest-heating can of each run at a given consistency. FMC consistometer (paddle A) readings are for the ingoing product and have been corrected to a temperature of 170°F. Readings greater than 100 have been extrapolated from actual data taken with the B paddle. The data indicate a definite decrease in sterilization value with increasing consistency at all reel speeds. All runs conducted at 5 rpm were processed for 22 min, 6 min longer than at other reel speeds. Even with the additional processing time, sterilization values for the tests conducted at 5 rpm were minimal at all FMC consistencies over 65 B.U., which represents about half the CSC tested. Heat penetration was greatly reduced at 5 rpm.

The effect of the reduced agitation on the measured heating rate parameter at 5 rpm is shown in Figure 5. At 10.6 and 8 rpm, the change in heating rate parameter over the range of consistency readings is relatively small. When the reel speed is 5 rpm, a dramatic change occurs in the heating rate parameter with increasing consistency. At low FMC consistometer readings, the heating rate parameter is about 12. But it increases to more than 30 when the consistency reaches 80 B.U. A single-valued heating rate parameter could not be shown in Figure 5 for the 6.5 rpm tests since broken-heating occurred.

DISCUSSION

THE OBJECTIVE of this investigation was to determine the effects of variation in processing parameters on the heating parameters and sterilization values of commercially formulated CSC heated in a Steritort. The study required that a large number of heat penetration tests be carried out during the 2-wk CSC pack. Since commercial CSC was used we did not have precise control of product formulation and true replicate or repeat tests could not be made.

For most processes, an initial run from a sample of CSC was followed immediately with a duplicate run. At the start of processing, initial temperatures of the CSC varied from 120 -175°F. The average initial temperature of the first run was 158°F. This temperature had dropped to 150°F for the duplicate runs because of the delay before filling the duplicate cans, even though filled cans were placed in a 170°F holding bath to await processing. The effect on the average sterilization value (general method) was a reduction of 1.5 min between initial and duplicate runs. When the Ball formula method (T_o = 170°F) was used, the difference was 0.5 min. This result indicated good agreement between duplicate runs, considering the possible rheological effects due to holding the product at elevated temperatures. Consistency readings for the ingoing product were corrected to a temperature of 170°F. F_o value comparisons are based on initial-temperature-corrected data. The data from minimum F_o value (slowest heating) cans are used in the discussion and figures.

Product agitation in a Sterilmatic cooker is a consequence of the motion of the headspace bubble within the can. For fill weights above 505g sterilization values are dramatically reduced (Fig. 2), even though gross headspace measured after processing is 0.25 in. (Fig. 1). Consequently, a positive indication of headspace after processing does not insure an adequate headspace during processing.

Within limits, the data show that the agitation and the rate of heat transfer increase with the reel speed. For a fixed-capacity cooker, however, an increase in reel speed is accompanied by a reduced retention (process) time. Whether this reduction is compensated by the increased heat penetration rate depends on the characteristics of the product being heated.

The effectiveness of the induced convection for CSC depends on accurate filling machines to control headspace, precise formulation and preparation to control product consistency, and avoidance of delays between filler and retort that tend to increase product consistency and lower initial temperatures (Kueneman, 1953; Wilson, 1953). Until recently, however, very few additional data on continuous agitating retorts have been published (Houtzer and Hill, 1977).

CONCLUSIONS

THE RESULTS of this investigation warrant the following conclusions regarding the processing of CSC in 303 × 406 cans in a Steritort:

1. Headspace is the most critical processing parameter. Regardless of consistency or reel speed, an inadequate headspace resulted in a low sterilization value. The critical nature of headspace suggests the use of positive headspacing devices or net-weight sensors for control on production lines.

2. Agitation of the product in the container is determined by reel speed. At reel speeds of 8 and 10.6 rpm, the effect of a change in consistency on heating rate was small. But at 5 rpm, the f_h value increased dramatically with increasing product consistency.

3. Consistency of CSC is influenced by both cream consistency and WDR, and both measurements are necessary to characterize the product completely. Devices that measure total product consistency such as the FMC consistometer and the Brookfield viscometer were helpful in establishing the effect of consistency on the sterilization value and can be used to establish consistency limits for effective processing.

REFERENCES

Adam, W.B. and Stanworth, J. 1939. Ann. Rept. Univ. Bristol Fruit and Veg. Pres. Res. Stn., p. 55, Campden. Quoted in "Canned Foods," Hersom, A.C. and Hulland, E.D., 1964, 5th ed., p. 147. Chemical Publishing Co., New York.

Houtzer, R.L. and Hill, R.C. 1977. Effect of temperature deviation on process sterilization value with continuous agitating retorts. J. Food Sci. 42(3): 775.

Kueneman, R.W. 1953. Continuous agitating retorts. Proc. Tech. Sessions 46th Ann. Conv. Natl. Canners Assoc., Feb. 21-24, 1953. In "Convention Issue," Information Letter No. 1426, Natl. Canners Assoc., Washington, DC.

Pflug, I.J. 1975. Procedures for carrying out a heat penetration test and analysis of the resulting data, p. 6—15. Univ. of Minnesota, Dept. of Food Science and Nutrition, Minneapolis, MN.

Wilson, C.K. 1953. Continuous agitating retorts. Proc. Tech. Sessions 46th Ann. Conv. Natl. Canners Assoc., Feb. 21-24, 1953. In "Convention Issue," Information Letter No. 1426, Natl. Canners Assoc., Washington, DC.

Ms received 8/5/78; revised 11/16/78; accepted 11/22/78.

Presented at the 38th Annual Meeting of the Institute of Food Technologists, Dallas, TX, June 4-7, 1978.

Scientific Journal Series 10,560, Minnesota Agricultural Experiment Station, St. Paul, MN 55108.

The authors express their appreciation to the Green Giant Company, and in particular to C.B. Way and R.D. Blanchett for supplying the product and the use of the research facilities that made this cooperative research effort possible. We also thank D.G. Neumann for his assistance in taking the data.