HEAT PENETRATION IN CANNED FISH

by

MYRON CARL DAVIS

A THESIS

submitted to the

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

May 1938

APPROVED:

Professor of Food Products Industries
In Charge of Major

Head of Department of Horticulture

Chairman of School Graduate Committee

Chairman of College Graduate Council

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Professor Ernest H. Wiegand under whose direction the work was undertaken; to Assistant Professor Thomas Onsdorff for his helpful suggestions and cooperation throughout the experiment; and to graduate students H. C. Aitken and K. Fenner for their assistance which made possible the photographic and photostatic prints in this thesis.

TABLE OF CONTENTS

ILLUSTRATIONS

HEAT PENETRATION IN CANNED FISH

INTRODUCTION

A valuable product of the North Pacific waters is canned salmon, which is a standard commodity in food markets of the United States. The largest can commonly sold is the one pound size. Considering the popularity and volume of sales of canned salmon it is only natural that larger containers would be of interest to packers. Large containers, such as are available for some meat products, would be advantageous for large families and consumers such as hotels and restaurants. Besides the convenience such a package would offer, there would also be a reduction in price per unit of fish due to container costs. As in the meat packing industry, there is the possibility of by-products for animal feeding from low grade raw materials and from pieces not suitable for regular grades. Large cans are even more desirable for by-products than for regular packs. A survey of the possibilities of such new canned products involves the question of preservation. Canning naturally would be the logical method of accomplishing preservation. With this view in mind, the following investigation was undertaken.

REVIEW OF LITERATURE

A review of the literature on heat penetration has shown that although the principle of preserving food with heat was discovered in 1810 by Appert (21) actual scientific studies were not undertaken until near the beginning of the present century.

Prescott and Underwood (19) in 1898 studied the souring of corn. Two facts were brought forth which apply in general to heat penetration into canned materials. First, the ratio of liquid to solid material in the can greatly influenced the rate of heat penetration. The second fact brought forth by their work was that regardless of the temperature of processing, the temperature in the center of the can reached that of the retort in approximately the same length of time.

Duckwall (8) in 1905 carried on heat penetration studies with peas. He also found that the temperature in the center of the can reached that of the retort in the same length of time regardless of the processing temperature.

Bitting (3) in 1912 pointed out that heat penetrated into substances containing free liquid more rapidly than it passed into materials of heavy consistency.

Bitting and Bitting (4) in 1917 investigated the effect of agitation upon heat penetration. They found that a minimum time was required to bring the temperature of the can to that of the bath where the proportion of free liquid allowed convection currents. The maximum time was required for products of consistency similar to that of mashed sweet potatoes. They also noted that with products of this type during an ordinary process time the center of the can rarely reached to within 10° C. of the retort temperature.

Thompson (22) in 1919 published a report on temperature-time relations during processing. This work is of interest because its purpose was to take the results and see what application could be made of a mathematical theory of heat conduction. He used the diffusitivity formula from which had been calculated the effect of size and shape of containers on heat penetration.

$$\text{Diffusitivity Constant } k = \frac{\text{Conductivity}}{\text{Specific Heat x Density}}$$

This diffusitivity constant is the numerical value of temperature change in a unit cube of material during a unit of time. He reported that in using this formula the assumption was made that all heat conducted was equally distributed throughout the cube. To use this formula based on conductivity it was also necessary to assume that convection currents would be local in character and that their effect would be equal to an increase in conduction. Due to the physical nature of food products varying convection and conduction conditions made the application of mathematics difficult. The author concluded that additional work on formulas would be required before results could be of practical use.

Ball (2) in 1928 developed a mathematical method of determining thermal processes of canned foods. Due to the varying physical natures of raw materials, the methods involved complicated mathematical formulas. He pointed out that the values obtained are purely theoretical, and that caution should be used in interpreting their results.

Magoon and Culpepper (17) in 1921 studied the factors affecting temperature changes in the container during the canning of fruits and vegetables. They found, as did earlier investigators, that the temperature of the retort is reached in the container in approximately the same time regardless of the processing temperature unless the higher temperatures broke down the tissues of the fruit as is the case with tomatoes. This study further indicated that the diameter of the container is of much less importance in material with free liquid than in those of heavy consistency. They pointed out that the character of the pack and the composition of materials were largely responsible for the rate of change of temperature at the center of the can. This change was rapid in materials with interspaces filled with free liquid, but with materials of heavy or pasty consistency the rate of change was very slow unless mechanical agitation was employed.

Joslyn (15) in 1928 made a study of the effect of viscosity in heat penetration. He found that except where heat brought about a change in colloidal substances the heating curve was always a record of change from a greater to a less viscosity while the reverse was true for cooling. He stated that the heat conductivity of liquids is low, and, that the major portion of the heat is transferred by convection currents. Greater viscosities decreased the rate of convection thus requiring heat penetration to proceed by the slower process of conduction. He observed the effects of viscosity and found that convection currents decreased as the center of the can approached the temperature of the retort. He also found that heat was transferred more slowly by conduction as the temperature at the center of the container approached the temperature existing near the wall of the container.

Lang (16) in 1935 reported an investigation of the thermal processes of California canned marine products. This work was concerned mainly with the time necessary to destroy an organism comparable in heat resistance to Clostridium botulinum. The heat penetration time resulting from this research showed that longer cooks were required to reach the maximum temperatures in the center of a solid piece of fish.

Hunter and Thom (14) in 1919 found in a bacteriological study of commercially canned salmon that a large percentage of the cans were unsterile and that over 40 percent contained an aerobic spore forming bacillus.

This investigation was of importance because it indicated that processing times being used were not sufficient to kill the dangerous, heat-resistant, Clostridium botulinum organism, if it had been present.

The Pacific Fisherman (18) in 1920 published a report of the National Canners Association on heat penetration differences between individual cans of the same size. This was explained by the probability that the point of the thermometer in some cases was in contact with the liquid while in others it was in a solid piece of flesh. Comparisons were made between cans started at room temperature and cans that had received an exhaust. These differences were largely overcome as the cans approached the retort temperature. The higher initial temperature added to the sterilizing value of the process given. Cans observed in the center of the retorts were found to heat as rapidly as those near the wall of the retort, provided it was properly vented. Fig. I shows the results of this investigation in graphic form.

So far as known no further studies of heat penetration in canned salmon have been made since those of the National Canners Association referred to above.

METHODS AND APPARATUS

Methods used in previous investigations. Ball

Reproduced by Permission from the Pacific Fisherman
Vol. 18, No. 7, 1920

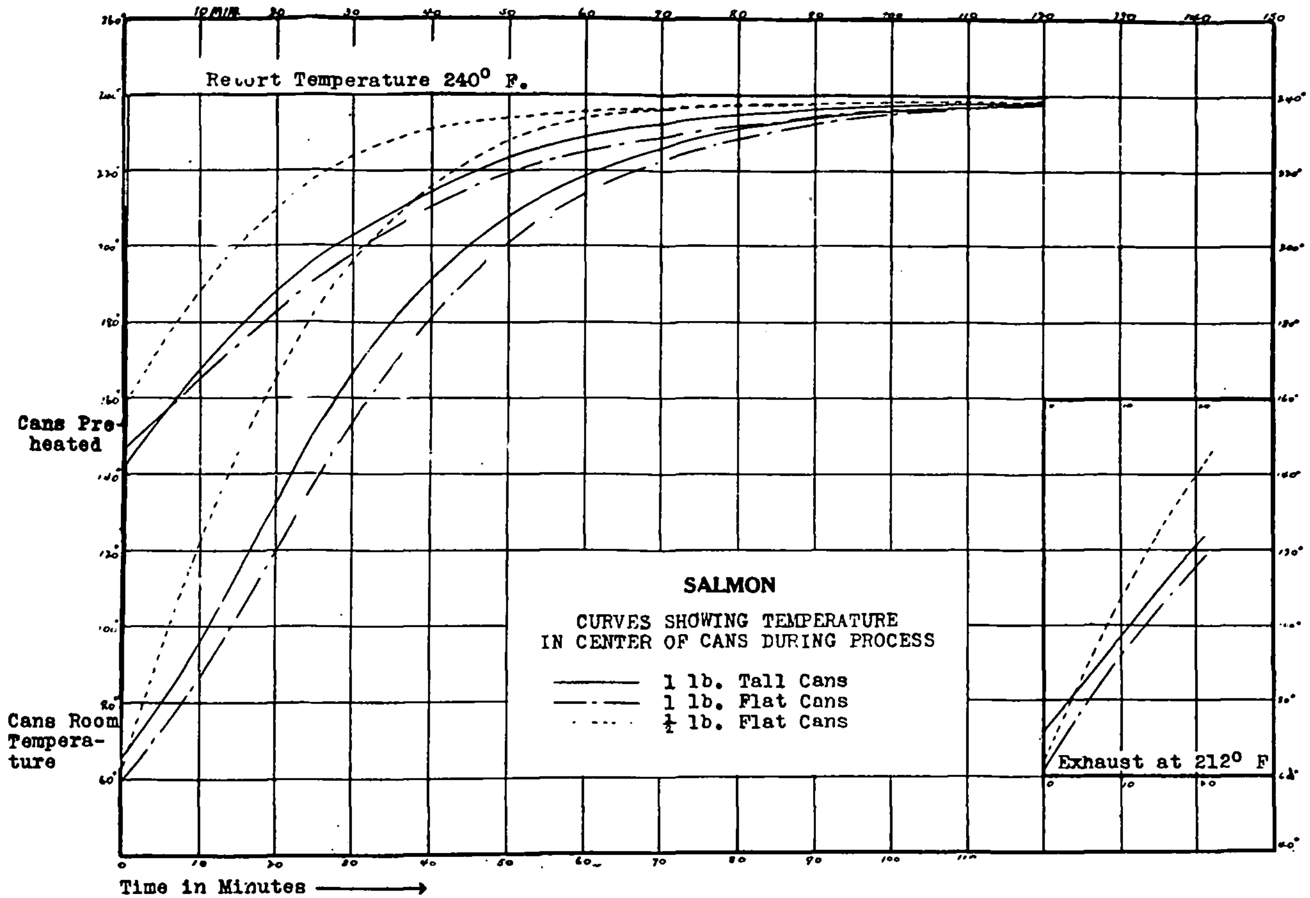


Fig. 1

(1) in 1938 enumerates various types of equipment that have been used in studying heat penetration such as maximum reading glass thermometers, ordinary glass thermometers, expansion thermometers, chemical indicators which undergo permanent color changes at certain temperatures, and materials that are melted at certain intensities of heat. These methods today are practically outmoded by the introduction and improvement of thermocouples.

Small special made maximum reading thermometers were used by placing them in the center of the contents of the can before sealing. Their readings were accurate, but only one temperatures was obtained from a can. A further disadvantage was that no method existed of accurately determining the length of time required to heat the contents of the can to the maximum temperature. This method was utilized by Prescott and Underwood (19) in 1898 but they had to use a large number of cans to obtain their final results.

Long stemmed thermometers were used by Bitting (3) in 1912 and also by Magoon and Culpepper, (17) in 1921. Apparatus for these experiments was so constructed that the thermometer was outside of the retort where it could be read continuously. The long stemmed thermometer was a decided improvement, but there were two outstanding disadvantages. Conduction occurred along the glass stem and the construction did not lend itself to studies in agitation.

Thermocouples were first tried by Bitting (3) in 1912 but were not successfully applied to this field until five years later by Bitting and Bitting, (4) in 1917. Bovie and Bronfenbrener (5) in 1919 developed a successful thermocouple apparatus for the measuring of heat penetration in canned foods.

Magoon and Culpepper, (17) in 1921 used thermocouples in conjunction with long stemmed thermometers. Since that time research in heat penetration has relied on thermocouples to obtain accurate results.

Principles of thermocouples. Seebeck (11) in 1821 discovered that in a closed circuit of two dissimilar metals there was a flow of electric current provided that the two junctions of the metals were at different temperatures. The magnitude of this electromotive force which may be measured by a potentiometer depends on three factors: First, the nature of the metals; Second, the difference in temperature of the two junctions; and, Third, the actual temperature of the two junctions. These are briefly the basic principles involved in thermocouples. Foote, Fairchild, and Harrison (12) in 1921 note that thermocouples, to be desirable, have to resist corrosion and oxidation, develop relatively large e.m.f., and have a temperature-e.m.f. proportionate to the increases in temperature.

Experimental Apparatus. Thermocouples were selected for this work on the basis of their superiority, accuracy and adaptability. Temperature mensurations within sealed rotated cans was impossible by other methods because of mechanical problems. The two metals used for the thermocouples in this experiment were copper and constantan. These metals, according to Foote, Fairchild and Harrison (12) in 1921, can be used for extreme precision work up to 360° C. Thermocouples for this experiment were made from special 24 gauge enamel wires supplied by Leeds & Northrup Company. The copper and constantan wires were fused together in an oxy-gas flame after being covered with sufficient melted borax to prevent oxidation. The junction formed was then placed on the end of an eight round fiber support, which had a diameter similar to that of a pencil. Two grooves were provided along the sides of the support in which the wires were led from the point of fusion. The remaining space was then filled with plastic wood. A short piece of fiber tubing was snugly fitted onto the outer end of the support to prevent the wires from tearing out of the grooves. After leaving the support each wire was covered with four feet of asbestos tubing which provided insulation until the wires from the three thermocouples were brought close together prior to their passing through the wall of the retort.

Passage to the outside of the retort was accomplished by using a multiple grooved rod of the same material and size as was used for the thermocouple supports. The grooves were filled with plastic wood after the wires had been inserted. Pieces of tight fitting fiber tubing were placed over the multiple grooved rod and passed through a stuffing box to the outside of the retort. Points on the inside of the retort where there was a remote chance that the rod could become damaged or shorted on the hollow metal drive shaft were covered with tubing.

Agitation experiments presented the problem of transferring the e.m.f. generated by the thermocouples through the revolving wires to a stationary instrument which would indicate the magnitude of the e.m.f. Provisions were made for the agitation studies by inserting a liquid medium between rotating and stationary wires in the following manner. A series of discs about an inch and a half in diameter were placed on the protruding end of the multiple grooved rod. The thermocouple leads now on the outside of the retort were each led to a seperate disc. Each wire was made to form a complete circle after it had passed through the radius of the disc. The circle of wire was then fitted into a groove on the circumference of the disc and securely fastened. A mercury bath was provided for each disc which allowed a minimum of a quarter of an inch immersion. Stationary leads from the potentiometer were placed in a part of the mercury where they did not inter-

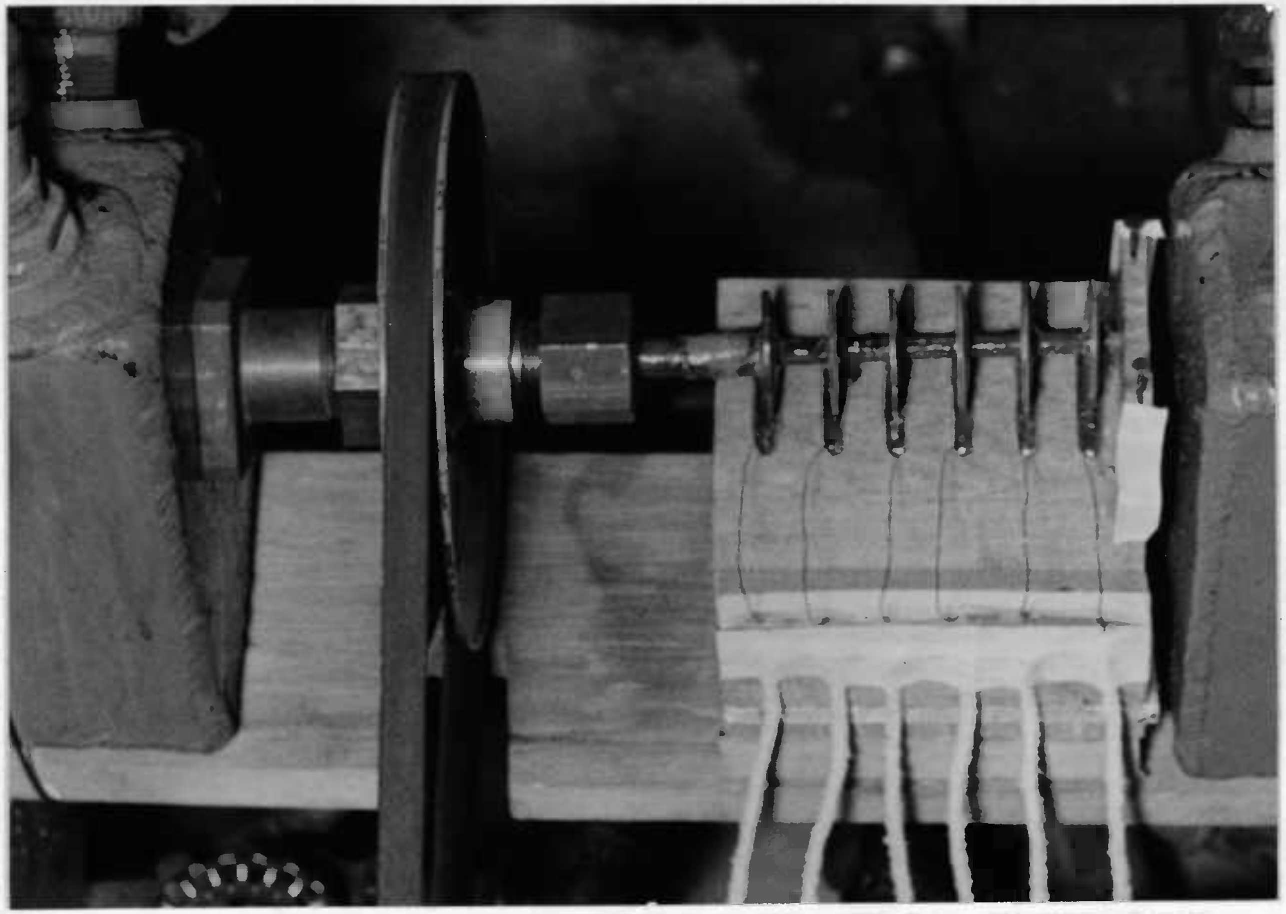


Fig. 2. Illustration of the mercury bath used for transferring e.m.f. from rotating to stationary wires.

fere with the rotation of the discs. Robinson (20) in 1938 indicated that from the standpoint of the thermoelectric characteristics there would be no effect on the e.m.f. if two ends of the thermocouple wire immersed in the mercury were at the same temperature. Fig. 2 illustrates the special equipment for transferring the e.m.f. from rotating to stationary wires.

Agitation was accomplished by means of a hollow shaft inserted through the wall of the retort. A square yoke was attached to the end of the hollow drive shaft inside the retort. This yoke supported woven wire baskets which were used to hold the cans during processing. Fig. 3. A stuffing box surrounded the shaft where it entered the retort to prevent the escape of steam. As the center of this shaft served as an outlet for the multiple groove rod containing the thermocouple leads another stuffing box was attached to the end of the shaft. Two purposes were served by this latter stuffing box: First, it prevented the escape of steam; and, Second, it held the multiple grooved rod stationary so that the discs attached to it rotated with the shaft. Fig. 2. Agitation was accomplished by placing a pulley on the shaft between the two stuffing boxes. Power for driving this pulley was transmitted by a V belt from a geared-in-head electric motor. All tests on agitated cans were made while the cans were being rotated at the rate of fifteen and a half revolutions per minute.

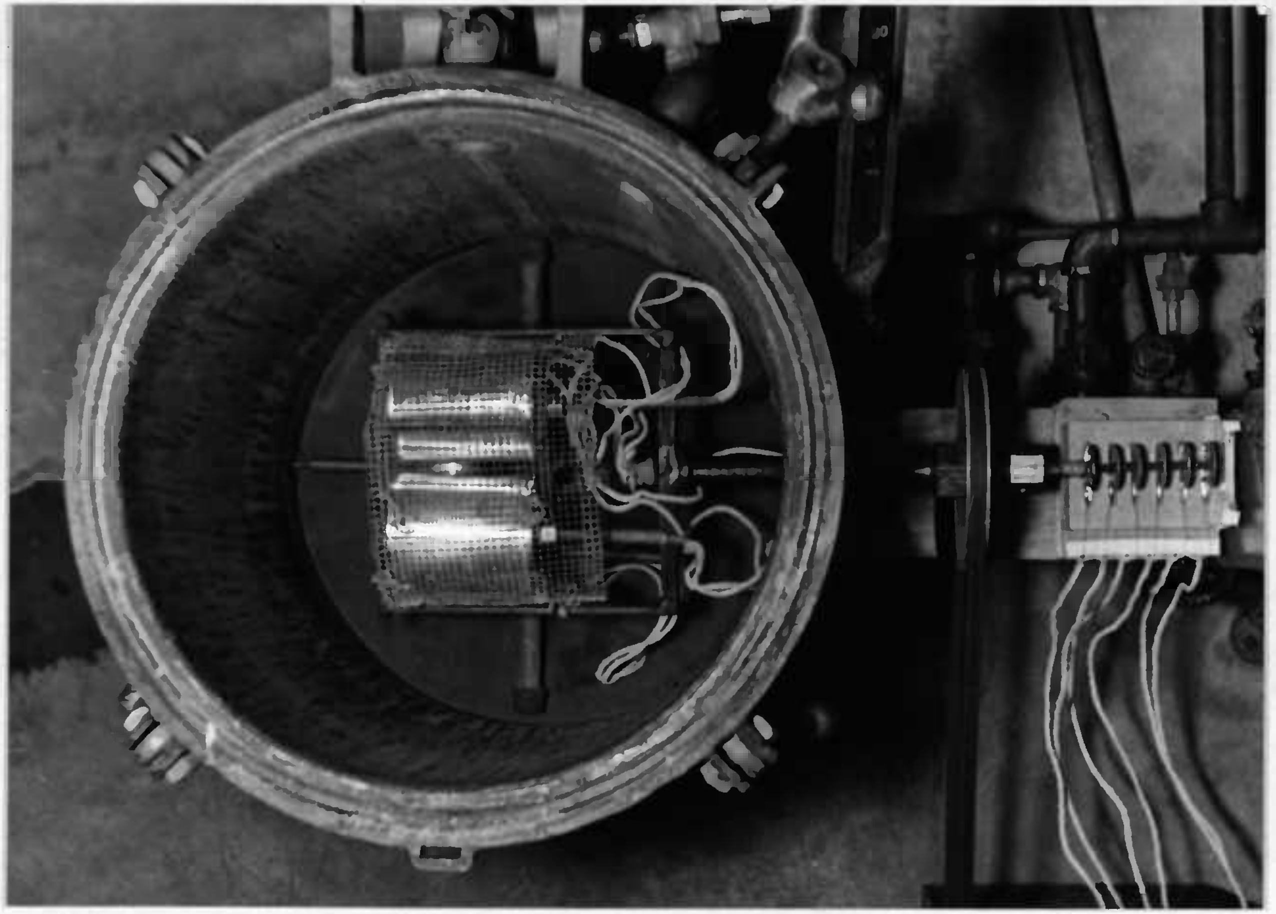


Fig. 3. Top view illustration of the mercury bath, drive shaft and location of cans and thermocouples in the retort.

Special tubular brass fittings were used to introduce the thermocouples into the cans. Fig. 4. The circumference of the tube was threaded the entire length except for a large, flat, hexagonal shoulder on one end. This shoulder fitted against the inside of the can and was held in place by a gasket and nut which was tightened down on the outside. The joint thus formed was tight so that no leakage occurred during the processing period which followed. A perfect seal was obtained around the thermocouple round fiber support by attaching a stuffing box to the outer end of the brass fitting.

The e.m.f. produced by the thermocouples was measured by means of a Leeds & Northrup portable potentiometer indicator. Fig. 5. The parts which appear on the outside of the instrument are as follows: A handle on the side for balancing the circuits; A galvanometer on the pannel for determining when the circuits of the potentiometer were in balance; A large dial for the millivolt readings; A small dial for the compensation of cold junction temperatures; Buttons to close circuits of the standard cell and of the thermocouple; and, Terminals for the connection of the thermocouple leads and for the connection of extra dry cells when the instrument is located in a stationary position.

A series of tests were run with the instrument before any experimental work was attempted. These tests were

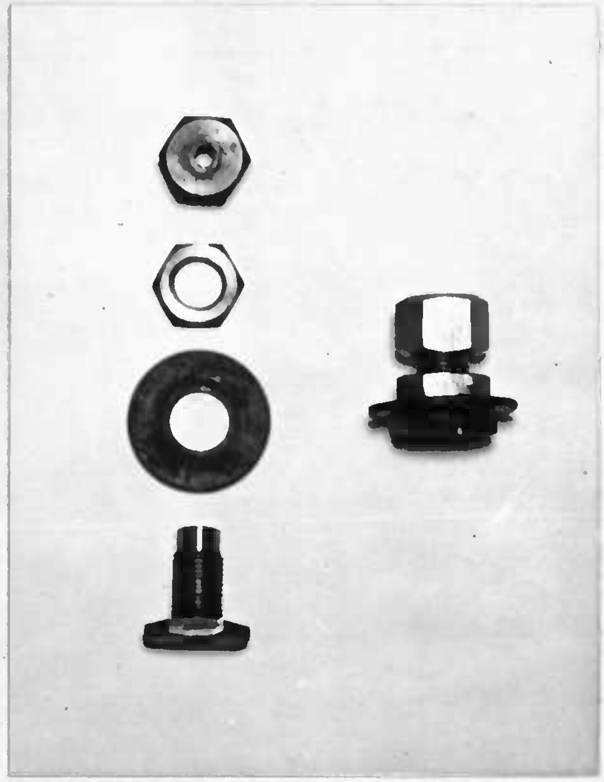


Fig. 4. Illustration of an assembled fitting and its separate parts.

Fig. 5. Portable potentiometer indicator.

checked against a Centigrade thermometer which had been calibrated to standard conditions and found to be correct. All potentiometer readings were based on Centigrade temperatures which were later converted to Fahrenheit when desired by the use of conversion Table XII. Preliminary tests were made with the compensator dial to determine the possibility of using room temperatures as the cold junction of the thermocouples. The potentiometer being used was calibrated so that at zero degrees Centigrade there would be no e.m.f. provided that the cold junction was at the same temperature. During calibration the hot junctions of the thermocouples were maintained at zero degrees Centigrade which gave them the theoretical value of zero, and thus any e.m.f. was a product of the cold junction which was the room temperature. The three experimental thermocouples with the mercury connections were also at this same time compared to a thermocouple with continuous wire leads, which is designated in Table 1 as number four. Thermocouple number four in many cases exceeded the others by a hundredth of a millivolt which was approximately equivalent to one-quarter of a degree Centigrade.

Table No. 1

Effect of Room Temperatures on Millivolt Readings

Room Temperature °C.	Theoretical Millivolt Reading	Millivolt Readings: Thermocouple Numbers 1	2	3	4
14	.56	.57	.57	.57	.58
17¼	.69	.69	.69	.69	.70
17½	.70	.70	.70	.70	.71
18½	.74	.75	.75	.75	.76
20	.80	.80	.80	.80	.81
20½	.82	.82	.81	.81	.81
21½	.86	.86	.86	.86	.87
23¾	.94	.95	.95	.95	.95
24	.96	.97	.97	.97	.97

The results as demonstrated in Table 1 compared favorably with the theoretical values which were taken from a table of Leeds & Northrup Company. Table No. XII. Since the experimental tests produced positive results the table of theoretical values was thereafter used to adjust the cold junction compensator for room temperatures.

Robinson (20) in 1938 stated that ordinary copper constantan thermocouple wire would match the temperature band of 32° to 225° F. to within 2° F. or 0.048 millivolts. Preliminary tests were run with the thermocouples at different temperatures to be used in the experiment and no variation of as much as 2° C. occurred. These results further substantiated the use of the theoretical table as a standard for the experiment.

The portable potentiometer indicators of the type used in this work are, according to Robertson (20) in 1938, accurate only to within 2° F. Accordingly, the final results cannot be claimed to be better than that of the potentiometer indicator. The preliminary tests previously cited would indicate, however, that this error was seldom approached.

PROCEDURE

Fresh Chinook salmon were used for all experimental tests except for the number 10 cans which were packed with Bluebacks. The fish after being prepared were filled into the cans by weight with the exception of the number 10's which were tightly packed. Table No. 2. The net weight of each of the number 10 cans was the same. An attempt was made when packing the cans to have the pieces of fish located in the can so that the thermocouple when inserted would be in the center of a large piece and at the center of the can.

Table No. 2

Fill of Experimental Cans

Product	Can Size	Weight Pounds	Oz.
Salmon	1 lb. Tall	1	0
Salmon	No. 2½	1	14
Salmon	No. 10	7	0

By-products were obtained by grinding the heads, tails, fins and other small cuts. This ground material was packed

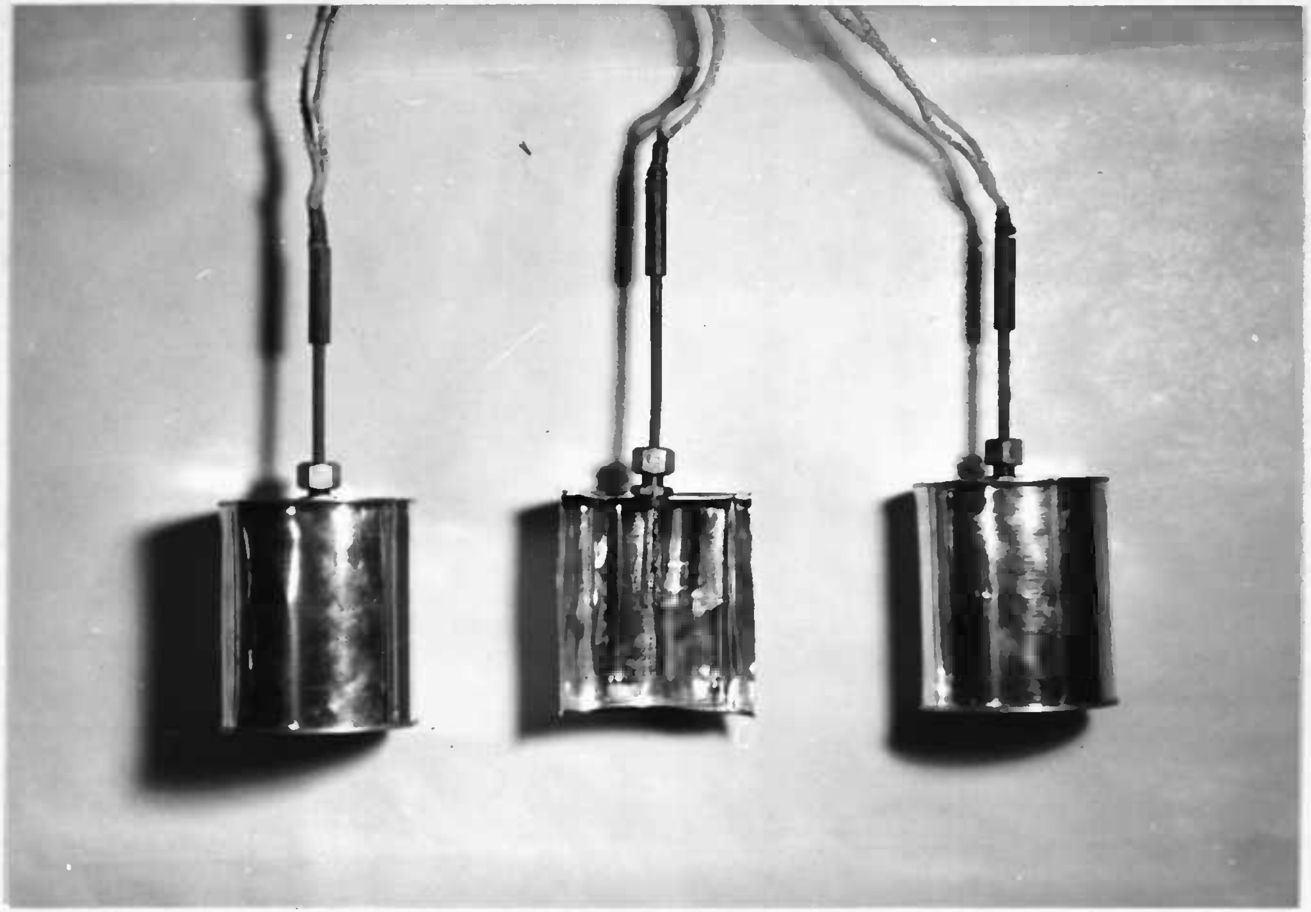


Fig. 6. Illustration of the position of thermocouples in the cans.

into cans moderately tight and handled in the same manner as the canned salmon.

The smaller sized cans were prepared for the experiments by attaching the brass fittings, Fig. 4, at the center of the bottom of the can, Fig. 6. The number 10 cans were handled slightly differently in that the special brass fitting box was attached at the side midway between the ends. After filling, the cans were sealed by double seamers available in the laboratory.

No provision was made for vacuum sealing in this experiment. Clark, Clough, and Shrostrom (6) in 1923 gave the following functions of vacumm in canned salmon: First, to keep the ends collapsed; Second, to prevent unnecessary strains; and, Third, to restrict and prevent the growth of certain bacteria. Since vacuum was not needed to serve any of the above mentioned functions the cans were not vacuum sealed.

The thermocouples were inserted through the opening provided in the brass fittings attached at the ends of the cans. Care was taken to have the hot junction in a piece of flesh, The cans containing the thermocouples were always maintained in the same location in the retort by placing them in a wire basket. The basket also served to hold the cans securely during the period when they were being treated by agitation.

A constant temperature was maintained in the retort

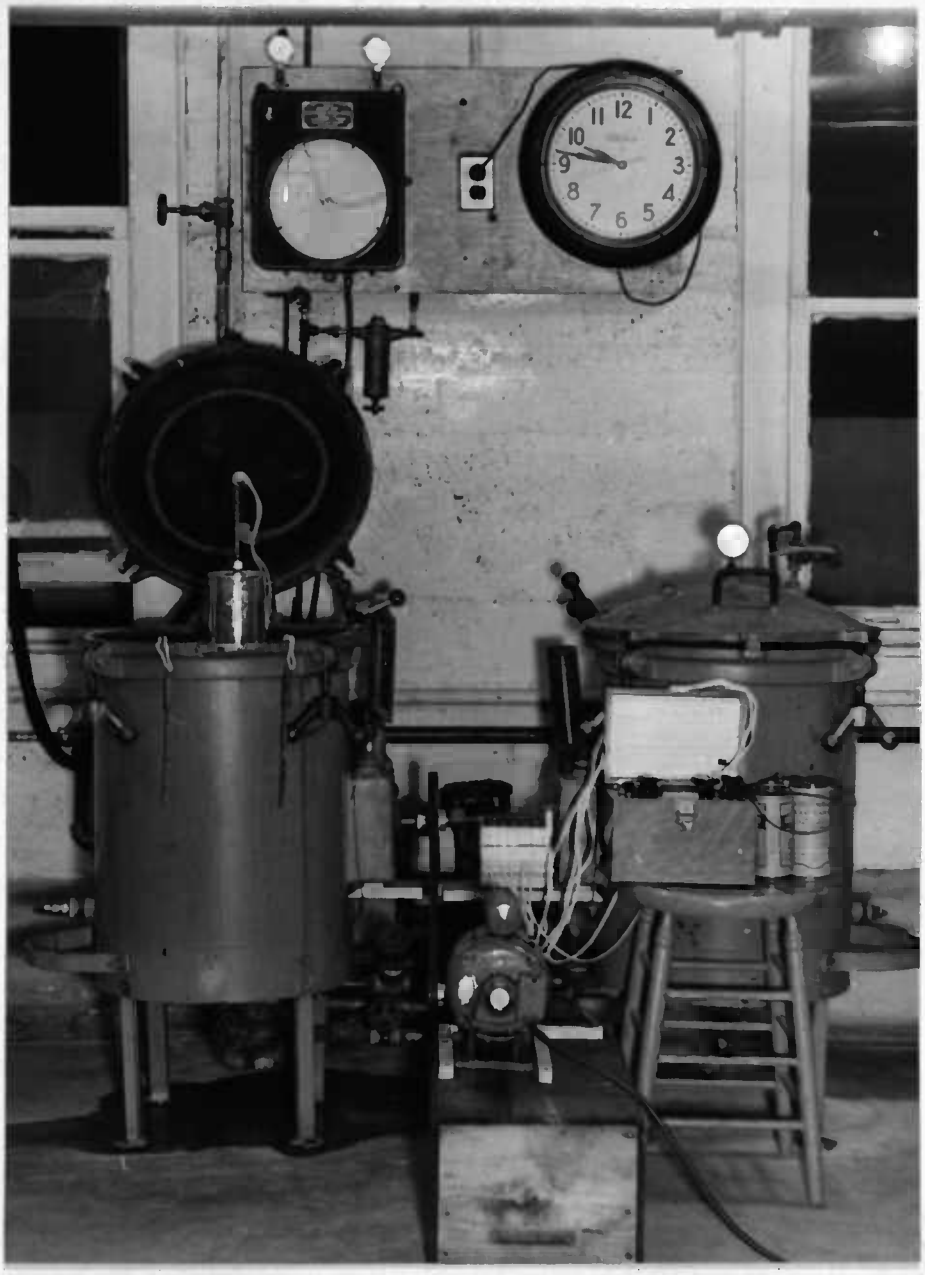


Fig. 7. Illustrates equipment used for studying heat penetration.

during the experimental runs by an automatic, air-operated, Tycos recording control unit. Fig. 7. Temperature readings were also taken from a seven inch mercury sight thermometer properly attached at the side of the retort. These controls were such as might be found in good commercial plants, and had been tested for accuracy with a thermometer from the Bureau of Standards.

Readings were made on the thermocouples every ten minutes when possible and oftener when the changes occurred rapidly. Time readings were taken from an electric clock. Fig. 7. The millivolt readings obtained were translated to their equivalent value of Centigrade temperature. Table No. XII. These Centigrade temperatures in turn were later converted to Fahrenheit readings (13).

DISCUSSION

The results of this experiment should not be interpreted in any manner as a definite recommendation of processing times. The results merely show the possibilities of processing salmon in containers larger than are now common. They also show that agitation during processing may increase the rate of heat penetration.

In general a time which might be suitable for processing is dependent largely on the time necessary to kill heat resistant spore forming bacteria. Clostridium botulinum is the organism which presents this problem in canned foods because it is not only resistant, but it also produces a deadly toxin. No outbreaks of botulism have ever been attributed to commercially canned salmon. Fellers (10) in 1926 reported that Clostridium botulinum would grow vigorously in canned salmon. Dickinson, Burke, Beck, and Johnston (7) in 1925 found that the heat resistance of spores of Clostridium botulinum showed a marked increase at high temperatures when heated in broth covered with a thin layer of oil. Lang (16) in 1935 noted that although the heat resistance of Clostrium botulinum in canned sea foods was in direct relation to its resistance in neutral phosphate. Fish suspensions in oil were an exception to the rule. He further found that there appeared to be no direct correlation in canned marine foods between the hydrogen-ion concentration and heat resistance when the pH limits were between 5.0 and 6.8. Weiss (22) in 1921 in studying free Clostridium botulinum spores found the young spores have the higher thermal resistance. He also reported that the longer spores are held near killing temperature the longer the period required for remaining live spores to germinate.

The foregoing investigations indicate that Clostridium botulinum could grow in salmon. Such being the case, sufficient heat would have to be applied to destroy the spores. Esty and Meyer (9) in 1922 determined the minimum destruction time and the maximum survival times for

Clostridium botulinum when the spores were produced under most favorable conditions.

Table No. 3

Resistance of Clostridium Botulinum Spores

Esty & Meyer (9)

Minimum Destruction Time Minutes	Maximum Survival Time Minutes	°C	°F
5	4	120	248
12	10	115	239
36	33	110	230
120	100	105	221
360	330	100	212

The minimum destruction time in Table No. 3 will be referred to in locating an approximate process time in the heat penetration studies to be discussed.

Salmon used for this survey were found to have considerable variation in initial temperature. This necessitated the deriving of a standard which could be taken as the starting temperature of all experiments. The arbitrary temperature selected was 65° F. In most cases this temperature of 65° F. had to be derived by locating its position between the two nearest readings. The designated temperature was selected for two reasons : First, direct comparisons could be made with work of previous investigators, Fig. 1, and, Second, this temperature closely approaches that of room temperature. The selection of 65° F. is further substantiated as the starting temperature be-

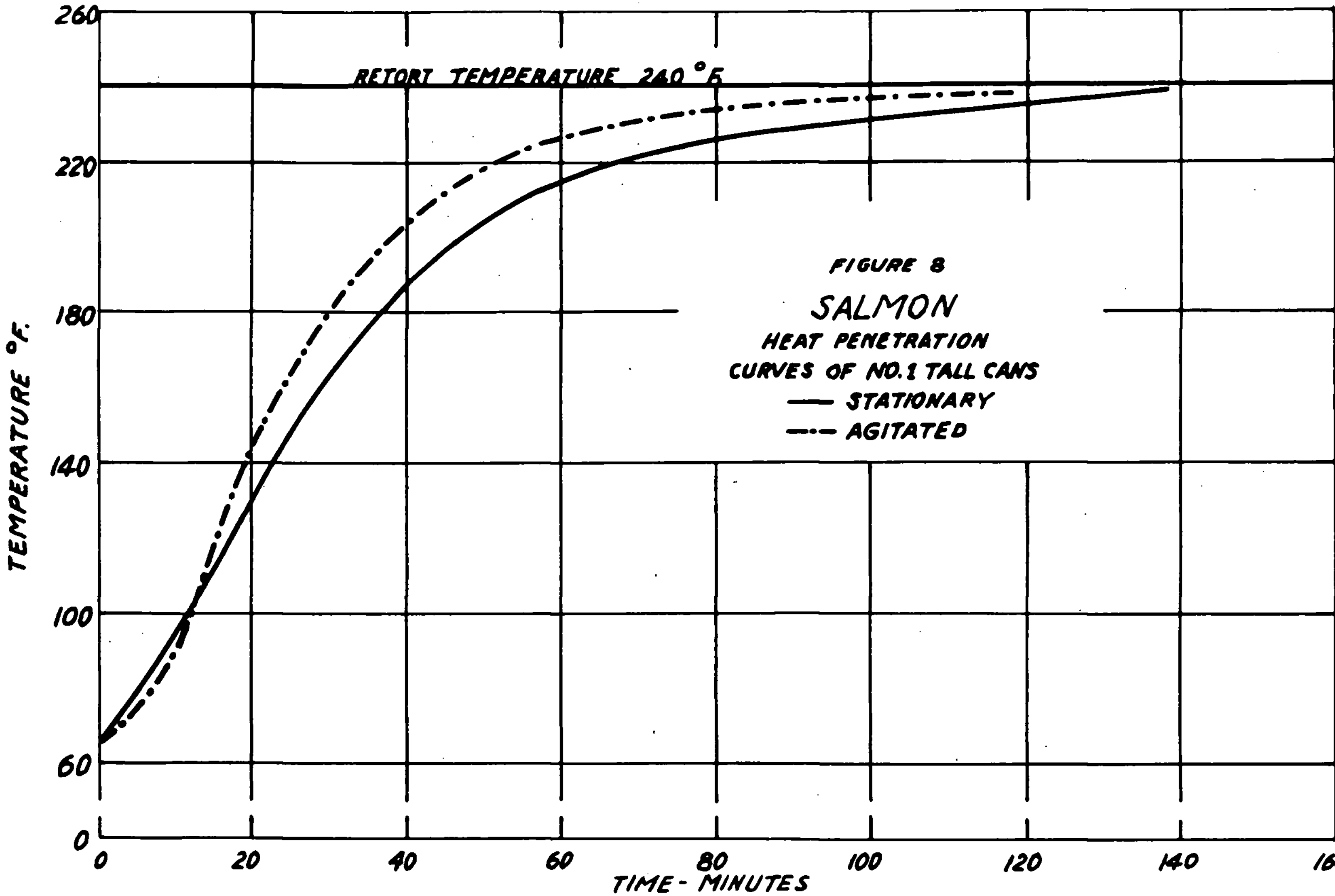


FIGURE 8
SALMON
HEAT PENETRATION
CURVES OF NO.1 TALL CANS

cause the salmon canning industry has of late years used mechnical vacuum and room temperatures rather than the older method of pre-heating to create a vacuum.

Time-temperature tables were made for each can run in all experiments. These tables appear for reference in the appendix. A summary and graph for each can would be confusing. Accordingly, the experimental results for all cans of each product were combined into average temperature and time. These averages were then plotted to form the heat penetration curves of the various products.

A series of fifteen number 1 tall cans of salmon, Table No. I, were processed in a stationary position to determine if the results of this experiment would be comparable to those previously reported in the Pacific Fisherman. Fig. 1. A survey of the heat penetration curves, Fig. 1 and Fig. 8, indicate that up to 160° F. the two curves are practically the same. Points on the curve beyond 160° F. deviate at times about 3° F. below those of the previous investigations. Close agreement of the two curves indicates that the methods used in this experiment gave results which compared favorably with those found by earlier investigators.

The series of stationary cans processed at 240° F. to obtain correlation with the former work were also compared with the series of fourteen similar cans which were agitated. Table No. II. The two methods seemed to maintain the same temperatures for the first ten minutes, after which heat penetrated into the agitated cans more rapidly. The variation caused by agitation was not great but, never-the-less, was significant when interpreted in terms of the minimum destruction time of Clostridium botulinum spores. Table 3. The agitated cans reached 230° F. twenty-five minutes before those that were stationary. The result of this was that the agitated cans passed through two-thirds of a minimum destruction time for that temperature before an equal temperature was reached in the stationary cans. The probability is that a processing period for agitated number 1 tall cans would be about twenty-five minutes less than for stationary number 1 tall cans.

The readings on agitated cans, Table No. II, were obtained by running three cans at a time. The cans were so arranged in the retort that when they were agitated two made large arcs while one in the center passed through a small arc. Cans number II, IV, VIII, XI and XIV, Table No. II, were located so that they passed through the small arc. No differences in heat penetration were observed between these cans and those passing through the large arc.

Number 2½ cans are larger than cans that are now being used for salmon. In-as-much as there was no standard weight for a can of this size, an arbitrary filling weight had to be selected. After a number of trials were

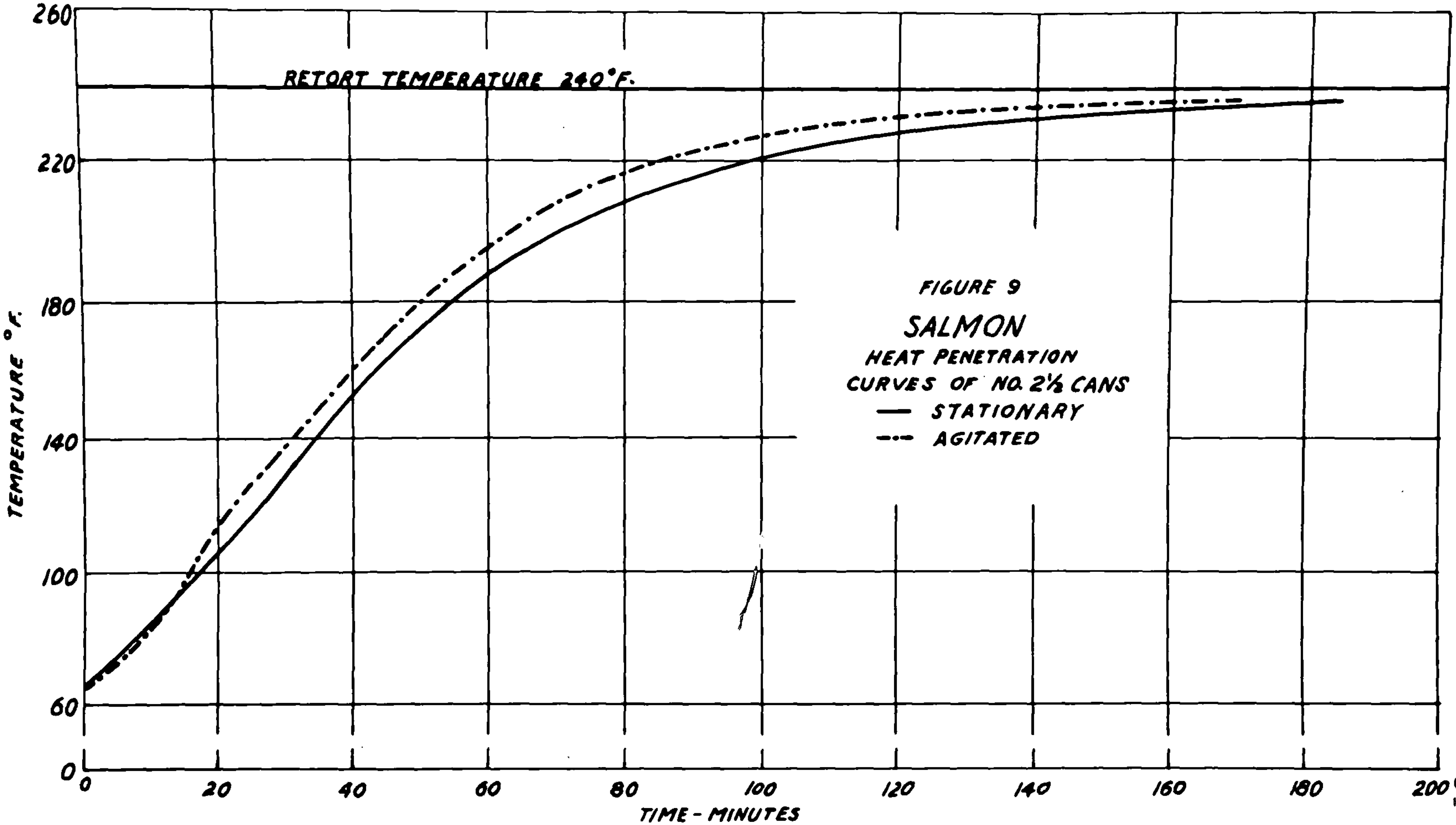


FIGURE 9

SALMON

HEAT PENETRATION CURVES OF NO. 2½ CANS

— STATIONARY

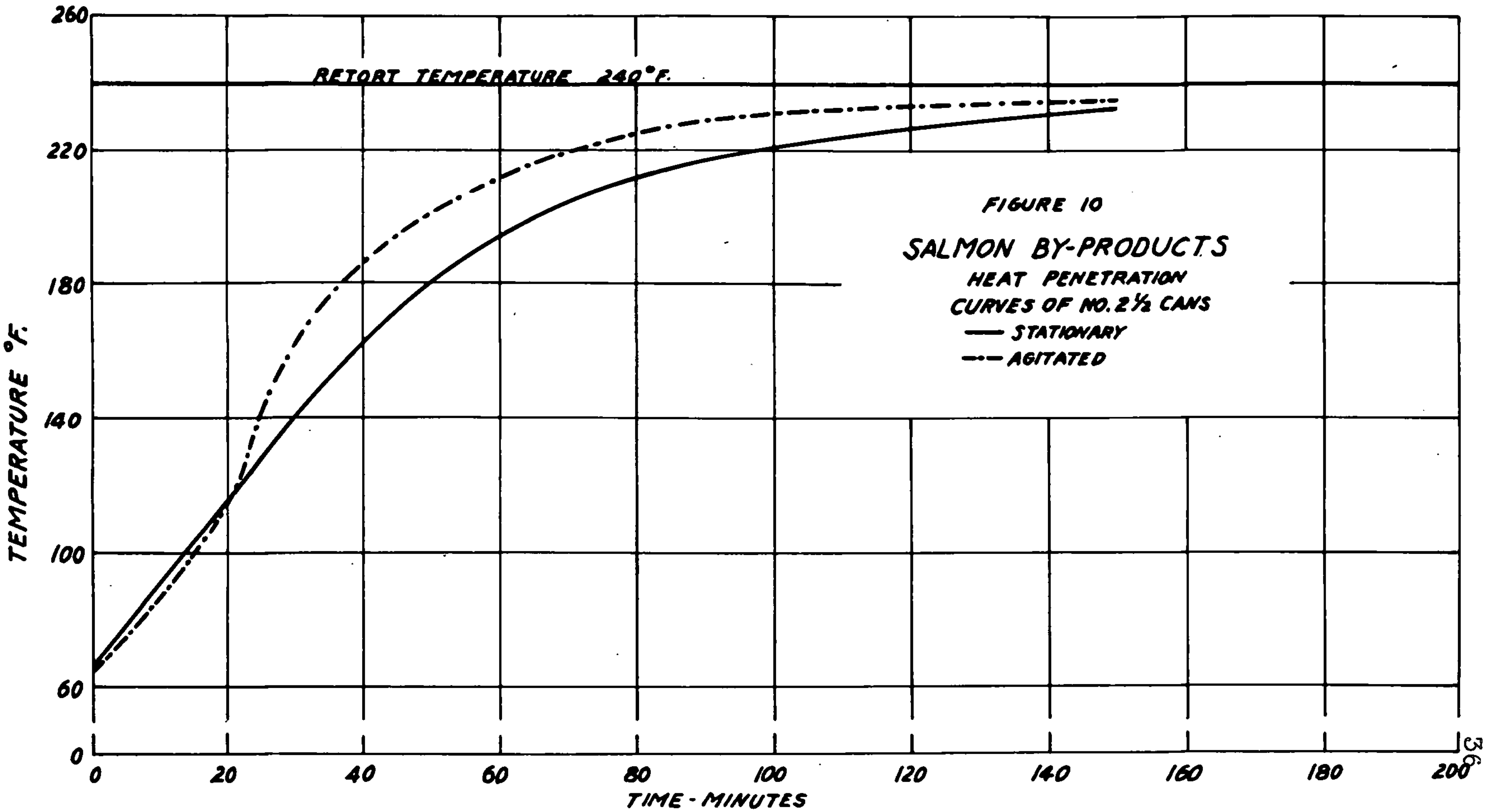
-·- AGITATED

made a weight of 1 pound and 14 ounces was selected as this was the maximum weight of bulky cuts which could be packed tightly in the can.

Seven number 2½ cans were processed at 240° F. in a stationary position. Table No. III. The average times and temperatures were taken from this table and plotted to form the heat penetration curve. Fig. 9. The results show that the center of the number 2½ cans reach 220° F. in a hundred minutes which was thirty-five minutes more than was required for number 1 tall cans under similar conditions. The time required to raise the temperature of the number 2½ cans from 220 to 230 degrees F. was thirty-five minutes. The time necessary for the destruction of the heat-resistance spores in this product, Table No. 3, indicates that a period of around 160 minutes would be necessary for processing.

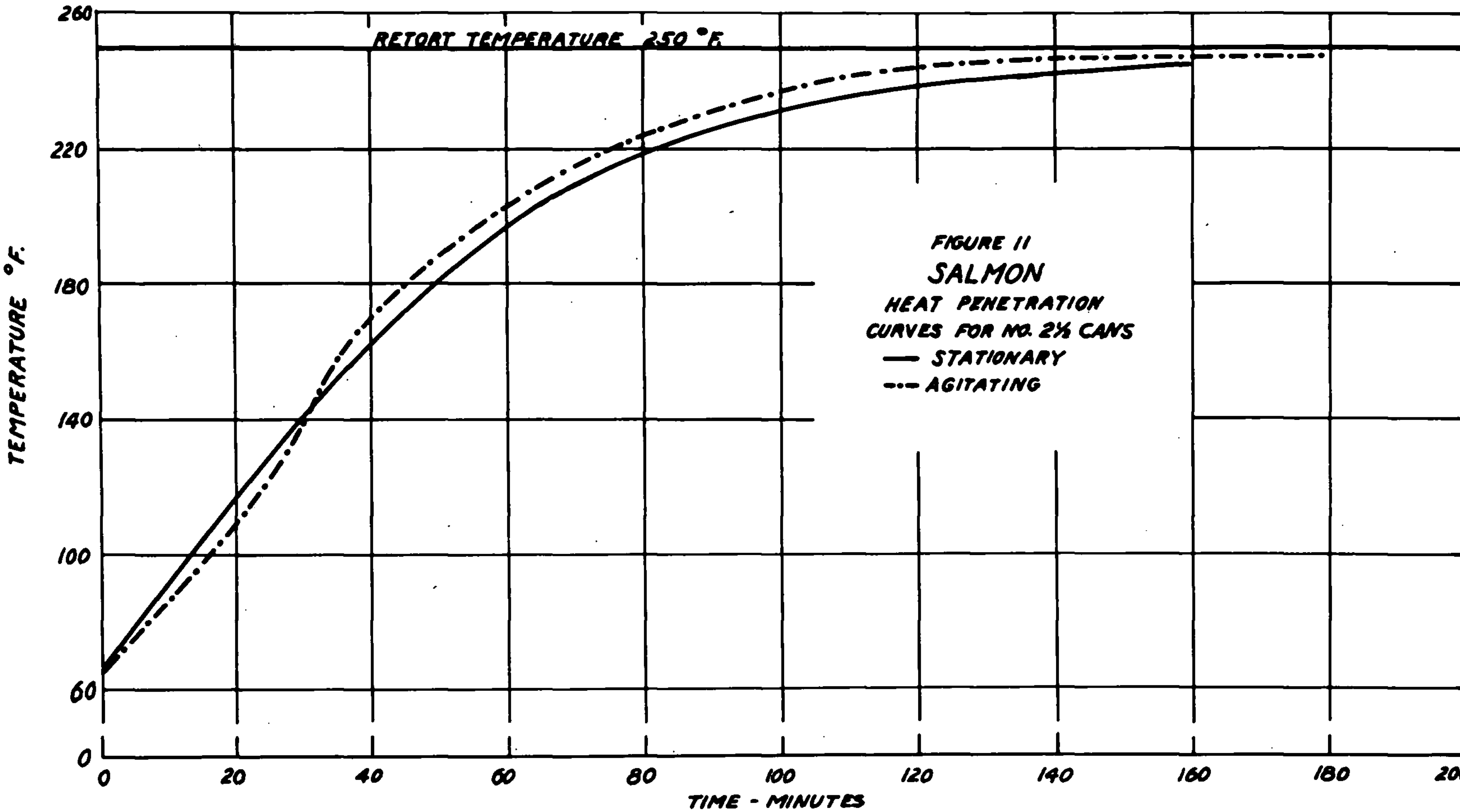
A group of number 2½ cans were processed at 240° F. for a period of 220 minutes. The center of these cans never reached the temperature of 238° F. The long processing period reduced the quality by making the fish dark and developed a burnt flavor which was most prominent in the juice.

A series of thirteen number 2½ cans were processed at 240° F. with agitation. Table No. IV. The average time-temperature curve did not rise above that of the stationary cans for the first twelve minutes. The two cur-


RETORT TEMPERATURE 240°F.
FIGURE 10
SALMON BY-PRODUCTS
HEAT PENETRATION
CURVES OF NO. 2½ CANS
STATIONARY
AGITATED
TEMPERATURE °F.
TIME - MINUTES
0
20
40
60
80
100
120
140
160
180
200
60
100
140
180
220
260

ves diverged after twelve minutes, but remained fairly close together and were of the same type. Fig. 9. As was the case of the number 1 talls, agitation here also brought the cans to the more lethal temperatures in a shorter time. The time required for the agitated cans to rise from 220 to 230 degrees F. was twenty-five minutes or ten minutes shorter than the time required for the stationary cans to pass through the same range. A processing period of 145 minutes would seem to cover the minimum destruction time of Clostridium botulinum spores. Table No. 3. This time is fifteen minutes less than that suggested as a possibility for processing stationary cans at the same temperature. The quality of the number 2½ cans processed with agitation at 250° F. did not appear to have been affected by the temperature.

Salmon by-products were made from the material left after the canning of the salmon. All by-products in these experiments were canned in number 2½ cans. Three cans were run in the stationary position at a processing temperature of 240° F. Table No. V. Their average time-temperature curve, Fig. 10, indicates that ninety-five minutes were necessary for the cans to reach 220° F. This is five minutes less than the time that was required for number 2½ agitated cans of salmon to reach the same temperature. Fig. 9. The temperature of 220° F. was also reached ten minutes sooner than it was in stationary cans of salmon


RETORT TEMPERATURE 250 °F.
FIGURE 11
SALMON
HEAT PENETRATION
CURVES FOR NO. 2½ CANS
STATIONARY
AGITATING
TEMPERATURE °F.
260
220
180
140
100
60
0
0
20
40
60
80
100
120
140
160
180
200
TIME - MINUTES

processed at 240° F. The time required for the cans to rise from 220 to 230 degrees F. was thirty-five minutes or the same as for stationary cans of salmon of the same size. If the rise from 220 to 230 degrees F. is considered as a quarter of the minimum destruction time for spores of Clostridium botulinum, the total time necessary would be about 160 minutes. This time would be the same as for stationary cans of salmon of the same size. Fig. 9.

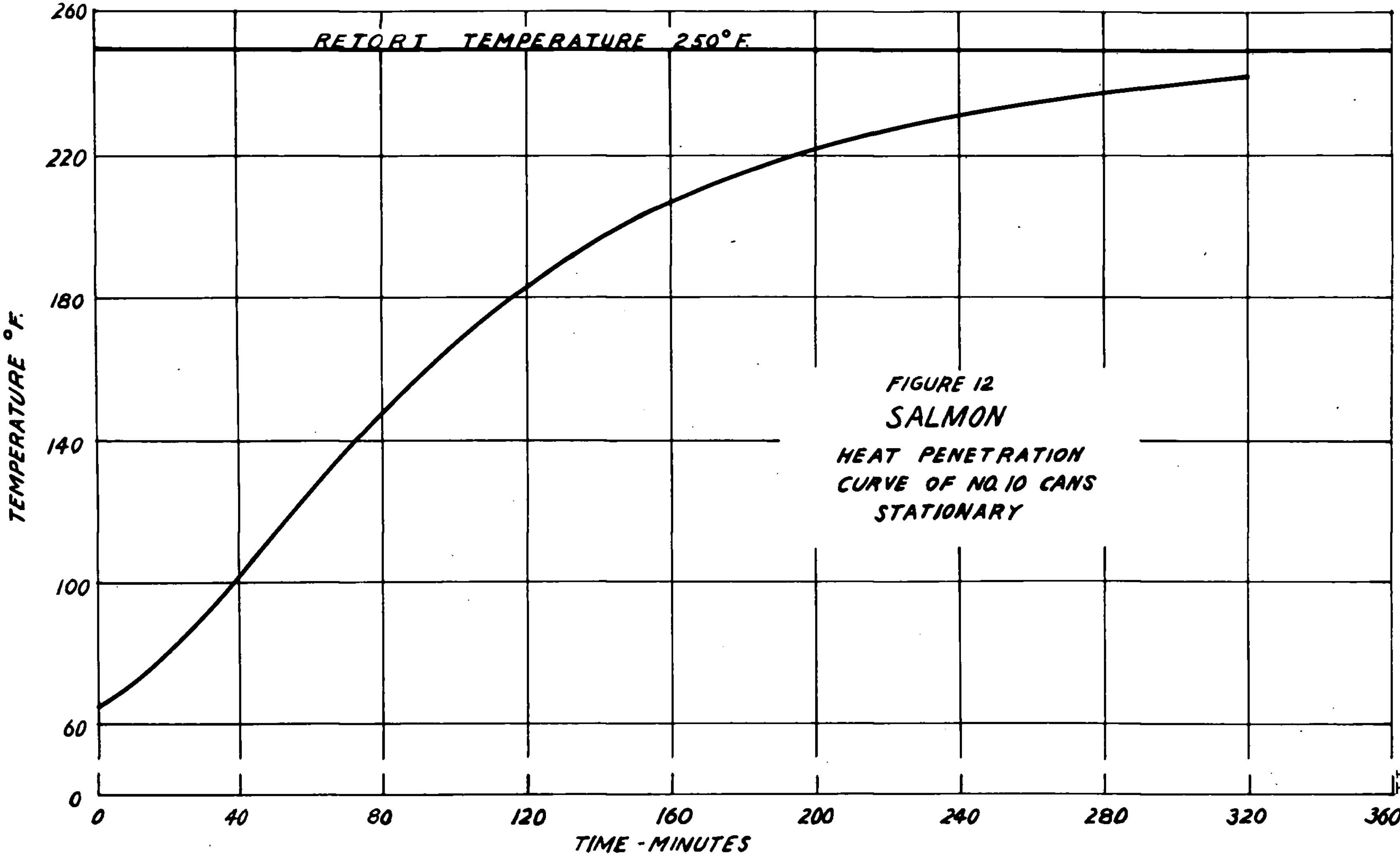
Four cans of by-products were processed by agitation at 240° F. Table No. VI. The average rate of heat penetration was the same as in the stationary cans during the first twenty minutes but after that a sharp variation occurred. These agitated cans reached 220° F. twenty-five minutes sooner than the corresponding stationary cans of by-products. The minimum destruction time given in Table No. 3 would seem to have been satisfied in this case after 120 minutes.

The possibilities of higher processing temperatures were studied. A temperature of 250° F. was selected since most canneries are so equipped that they could run their retorts at this temperature.

A series of five number 2½ cans of salmon were processed in a stationary position at 250° F. Table No. VII. The heat penetrated to the center of these cans during the first hour about as rapidly as the same size agitated cans of salmon processed at 240° F. Beyond this point the higher retort temperature changed the shape of the curve. Fig. 11. A lapse of time of about fifteen minutes was required for the temperature at the center of the can to rise from 220 to 230 degrees F. The temperature at 130 minutes was above 240° F. and had been sufficiently high for a long enough period so that the destruction time for the heat-resistant spores Clostridium botulinum was satisfied.

The agitated series of seven cans processed at 250° F., Table No. VIII, heated a little more slowly than the stationary cans for the first thirty minutes, but after that time heat penetrated into them more rapidly. Fig. 11. The slightly higher temperatures obtained by agitation, however, were in a range more destructive to heat resistant spores. Approximately fifteen minutes were required for the average temperature in the center of the can to change from 220 to 230 degrees F. which was the same as for stationary cans. By referring to Table 3 again the agitated cans appear to have passed through the minimum destruction time for Clostridium botulinum spores in 120 minutes. The gain in time by agitation over that of stationary cans was ten minutes.

Four number 2½ cans filled with salmon by-products were processed at 250° F. Table No. IX. This lot processed in a stationary position produced a heat penetration curve, Fig. 13, which was slightly below that of the lot


RETORT TEMPERATURE 250° F.
FIGURE 12
SALMON
HEAT PENETRATION
CURVE OF NO. 10 CANS
STATIONARY
TEMPERATURE °F.
260
220
180
140
100
60
0
0
40
80
120
160
200
240
280
320
360
TIME - MINUTES

packed with salmon having the same treatment. About fifteen minutes were required for the temperature of the cans to rise from 220 to 230 degrees F. This time was the same as the stationary lot of number 2½ salmon processed at the same temperature. A processing period for these by-products should be 135 minutes to satisfy the minimum destruction time given in Table No. 3. This time of 135 minutes exceeds by five minutes that of the stationary cans of salmon processed at 250° F.

Agitated cans of by-products were processed at 250° F. Table No. X. Their average temperature-time relation shows that the heat passed into them quite rapidly. Fig. 13. Only seven minutes were required for the cans to pass from 220 to 230 degrees F. By the end of seventy minutes the temperature at the center of the cans had been at lethal temperature long enough to satisfy the minimum destruction time of resistance spores of Clostrodium botulinum. Table No. 3.

Salmon were processed in number 10 cans to determine the effect of increased volume and weight on heat penetration. Three of these cans were processed in a stationary position at 250° F. Table No. XI. The heat penetrated into these cans slowly. Fig. 12. A period of two and one-half hours elapsed before the cans reached 212° F. The center of the cans required fourty minutes to rise from 220 to 230 degrees F. and a total of four and one-half hours

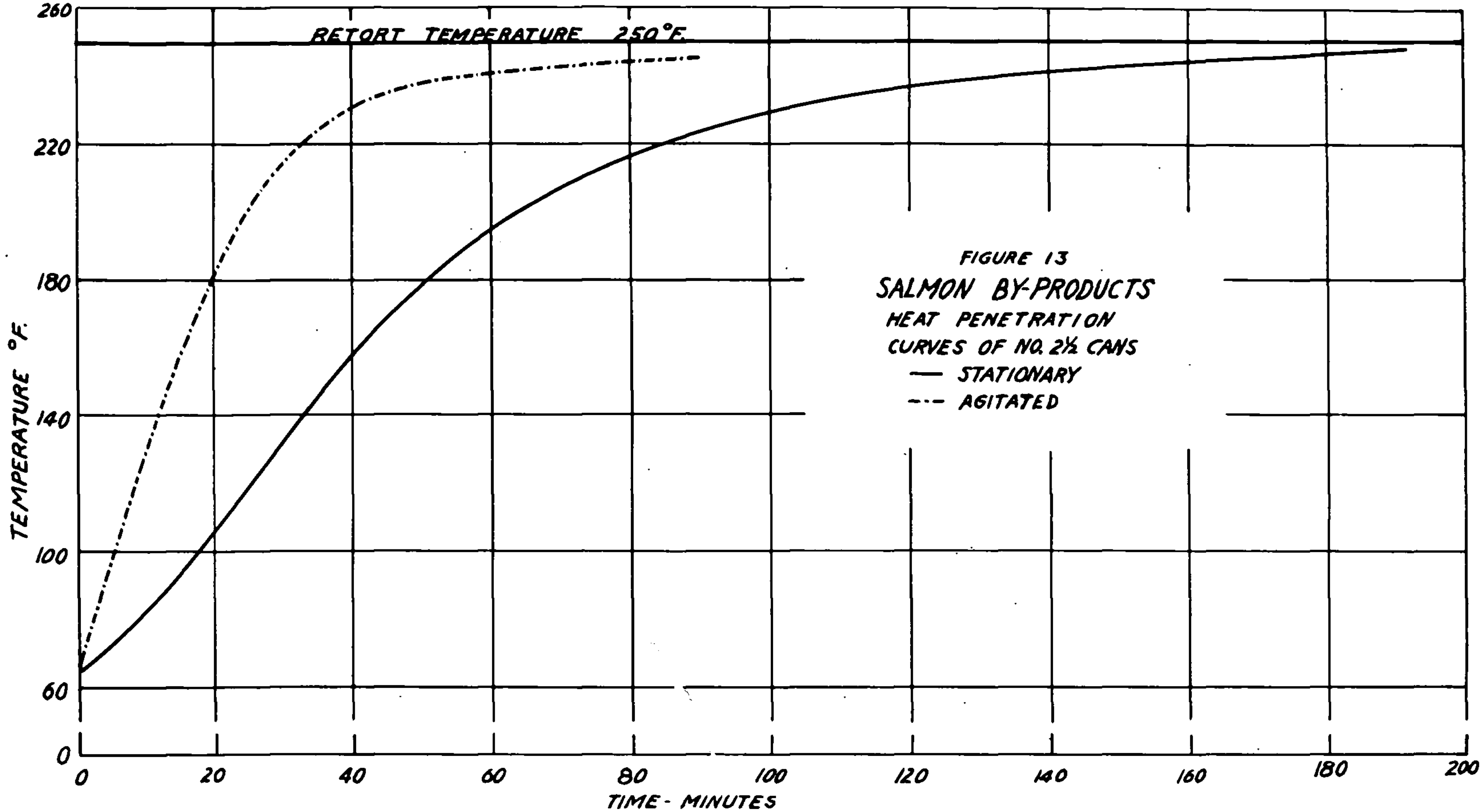


FIGURE 13
SALMON BY-PRODUCTS
HEAT PENETRATION CURVES OF NO. 2½ CANS

were necessary before the minimum destruction time in Table No. 3 had been satisfied. The number 10 cans did not reach 240° F. until after they had been processed five and one-quarter hours. The cans were processed for an excessive length of time in this experiment. This was done to obtain a long curve which would show the resistance of the contents to rise in temperature. The final product after this long process was soft and the liquid had a burnt flavor.

A discussion of the experimental work as a whole would be mainly a repetition of what has already been previously presented. One factor still seems to present itself though in a survey of the work. All of the agitation experiments with but one exception had the same rate of heat penetration as the stationary cans during the first few minutes. An explanation of this at the present time can only be presented as theory. Salmon is packed as a solid piece of flesh with no liquid. After processing the flesh is loose in the can and considerable water and oil are present. Considering this it is probable that during the first few minutes of cooking the heat penetrated by conduction whereas after liquid was formed heat penetrated more rapidly because of the development of convection currents. This would seem to indicate that there is some benefit derived from agitation.

SUMMARY

1. Successful equipment was developed for this experiment which allowed thermocouples to be used while they were in cans that were being agitated.

2. Preliminary tests indicated that the results obtained are comparable to those of a previous investigator.

3. Agitation which was carried out at fifteen and a half revolutions per minute decreased the time necessary for a processing period.

4. Stationary cans of salmon and stationary cans of by-products both required about the same processing time

5. Processing time of salmon and salmon by-products was reduced by raising the processing temperature from 240 to 250 degrees F.

6. Agitated salmon by-products heated more rapidly a all temperatures than agitated cans of salmon.

7. Number 10 cans were extremely slow in reaching a temperature which would assure the destruction of heat-resistant Clostridium botulinum spores.

8. The times that are considered sufficient in this survey are not intended in any manner to be recommendations of processing times for the product considered.

BIBLIOGRAPHY

(1) Ball, C. O. Advancement in Sterilization Methods for Canned Foods. Food Research, 3, 1 and 2: 13-55, 1938.

(2) Ball, C. O. Mathematical Solution of Problems on Thermal Processing of Canned Food. University of California Publications in Public Health, 1, 2: 15-245, 1928.

(3) Bitting, A. W. The Canning of Foods. U.S.D.A. Bulletin 196. 1-79, 1912.

(4) Bitting, A. W. and Bitting, K. G. Bacteriological Examination of Canned Foods. National Canners Association Bulletin 14. 1-47, 1917.

(5) Borie, W. T. and Bronfenbrener, J. An Apparatus for Measuring Heat Penetration. Journal Industrial and Engineering Chemistry. 11, 6:568-570, 1919.

(6) Clark, E. D., Clough, R. W., and Shrostiom, O. E. The Function of Vacuum in Canned Salmon. National Canners Association. 1-31, 1923.

(7) Dickinson, E. C., Burke, G. S., Beck, D., and Johnson, J. Spores of Clostridium Botulinum. Journal of Infectious Diseases. 36:412-483, 1925.

(8) Duckwall, E. W. Canning and Preserving Food Products With Bacteriological Technique. 1, 1905.

(9) Esty, J. R. and Meyer, K. F. The Heat Resistance of Clostridium Botulinum and Allied Aerobes. Journal of Infectious Diseases. 31:650-663, 1922.

(10) Fellers, C. R. A Bacteriological Study of Canned Salmon. Journal of Bacteriology. 181-202, 1926.

(11) Ferry, E. S., Shook, G. G., and Collins, J. R. Practical Pyrometry. 1-70. John Wiley and Sons Inc. 2nd edition revised 1920.

(12) Foote, P. D., Fairchild, C. O., and Harrison, T. R. Technologic Papers of the Bureau of Standards No. 170. 1-325. Government Printing Office, Washington D. C., 1921.

(13) Hodgman, C. D. and Lange, N. A. Handbook of Chemistry

and Physics. 1150-51. Chemical Rubber Publishing Co. Cleveland, Ohio. 13th edition, 1928.

(14) Hunter, A. C. and Thom, C. An Aerobic Spore-forming Bacillus in Canned Salmon. Journal of Industrial and Engineering Chemistry. 11, 7:655-57, 1919.

(15) Joslyn, M. A. The Role of Viscosity in Heat Penetration. The Fruit Products Journal and American Vinegar Industry. 7, 9:16-19, 7, 10:22-4, 7, 11:13-15, 1928.

(16) Lang, O. W. Thermal Processes for Canned Marine Products. University of California Publications in Public Health. 2, 1:1-167, 1935.

(17) Magoon, C. A. and Culpepper, C. W. A Study of the Factors Affecting Temperature Changes in the Container During the Canning of Fruits and Vegetables. U.S.D.A. Bulletin 956. 1-55, 1921.

(18) The Pacific Fisherman. Temperature Experiments in Canning Salmon. The Pacific Fisherman. 18. 7: 51-52, 1920.

(19) Prescott, S. C. and Underwood, W. L. Contributions to Our Knowledge of Micro-organisms and Sterilizing Processes in the Canning Industry. Tech. Quarterly. 11, 1:6-30, 1898.

(20) Robinson, J. W. Personal Communications Representing Leeds and Northrup Company, San Francisco, California, 1938.

(21) Tanner, F. W. The Microbiology of Foods. 526-27. Published by Twin City Publishing Co., Champaign, Ill. First edition 1932.

(22) Thompson, G. E. Temperature-time Relations in Canned Foods During Sterilization. Journal Industrial and Engineering Chemistry. 11, 7:657-64, 1919.

(23) Weiss, Harvey. Heat Resistance of Spores of Bacillus Botulinum. The Journal of Infectious Diseases. 28:70-92, 1921.

APPENDIX

Table No. I, Section I

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
0	65.3	64.7	64.7	64.8	64.9	64.9	64.4
1					65.8		
-							
5			71.6				84.7
6							
7	74.3					83.8	
8				85.6			
9					96.4		
10		80.6					
11							
12					104.0		110.8
13			82.9				
14	92.3						
15				112.1			
16		95.5				113.0	
17			97.7				128.8
18							
19	109.9						
20					136.4		
21							
22							144.5
23		121.1					
24			124.9				
25							
26					154.9	146.8	
27							
28	144.5						
29				161.6			
30					168.4		
31		151.3				161.2	
32							168.4
33			155.5				
34						172.0	
35							
36	167.9						
37							179.2
38		173.5	172.0	194.4			
39							
40					198.7		

Table No. I, Section I

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
41							
42	182.5			199.8			
43					203.7		
44						199.0	
45		189.0					
46			188.2	204.8			194.4
47						203.7	
48	193.6						
49				209.3			
50							
51		199.0			212.7		
52			196.3				
53							
54	201.7						203.7
--							
58				217.8			
59							209.3
60					218.5	217.4	
61		213.1					
62							
63				221.4			
64					221.0	220.6	
65							214.3
--							
69		218.5	217.0				
70							217.0
--							
73	222.4						
74						223.9	
75				224.6			
76					224.6		
77		226.0					
78			224.2				220.1
79	224.6						
80				224.6		225.9	
81							
82		227.5			225.0		
83			226.8				

Table No. I, Section I

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
84					225.5	226.0	
85	226.8						
86							
87		230.9	229.5				223.9
--							
95							226.0
--							
145							

Table No. I, Section II

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall Retort Temperature--240° F.

Time	Can Numbers							
	VIII	IX	X	XI	XII	XIII	XIV	XV
Min.	°F	°F	°F	°F	°F	°F	°F	°F
0	64.7	65.4	64.4	65.7	64.0	64.5	65.6	65.5
1								
2							72.1	
3				70.3				
4						73.9		76.1
5					76.7			
6	77.9							
7		85.1	83.8					
--								
11	100.0						107.6	
12						109.0		
13		112.1						109.0
--								
16							124.5	
17				121.1				
18	127.0		118.9		125.6	132.8		126.1
19								
20		136.0						
21								
22				140.9				
23								
24	144.1				146.3			
25		151.3	143.6					
26							163.4	155.8
27								164.4
28								
29				163.0				
30								
31	167.5				166.6			
32							173.5	
33								
34		174.7	167.9			184.1		173.1
--								
38	181.0							
39		183.7		186.8				
40			178.2		187.3		189.0	
41								
42						200.8		186.8

Table No. I, Section II

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall   Retort Temperature--240° F.

Time	Can Numbers							
	VIII	IX	X	XI	XII	XIII	XIV	XV
Min.	°F	°F	°F	°F	°F	°F	°F	°F
43	190.8							
44				195.1				
45		193.6			195.1			
46								
47							198.7	
48								195.4
49			195.1			210.9		
--								
52	205.3							
53		207.1		209.3				
54	211.3							
55		210.6						
56					212.0		212.0	
57			204.8					
--								
60								210.9
61						222.1		
--								
64				219.2				
65	217.0							
66								
67		217.8						
68					217.8			220.6
69								
70	218.8						227.8	
71			217.8					218.8
72		219.7						
--								
75				225.5				
76	222.8						225.0	
77			218.8		224.2	230.0		
78								222.1
79		222.4						
80								
81			220.6	226.8				
82					225.3			
--								
85				228.9				
86	226.4							

Table No. I, Section II

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--1 lb. Tall   Retort Temperature--240° F.

Time	Can Numbers							
	VIII	IX	X	XI	XII	XIII	XIV	XV
Min.	°F	°F	°F	°F	°F	°F	°F	°F
87								
88							230.9	
89		225.0			228.6	235.0		228.9
--								
92			225.0					
93	228.2							
94								
95		226.0						
96								
97				230.0			232.5	
98			226.4		229.6	235.8		
99								230.4
100								
101				231.8				
102					229.6			

105							235.0	
106								234.1
107						237.9		

110			232.2		234.1			
111								
112			232.2					
113					234.5		236.1	
114						238.6		
115				236.1				234.1
116					235.4			

124							238.3	
125								236.5
126						238.6		

135							238.6	
136						238.6		237.6

143							239.9	
144								239.0
145						239.9		

Table No. II, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
0	65.0	65.4	65.0	64.9	64.7	65.0	65.2
1						66.2	67.1
-							
4					68.9		
-							
7		86.5					
8			72.1	83.8			
9							91.9
10						85.6	
--							
14							112.6
15						105.8	
16					113.5		
--							
19	139.6	131.4	116.2				
20				137.5			
--							
23					144.5	142.3	
24							
25	164.5						
26							
27							161.2
28		165.2	157.1	167.0			
--							
31					169.9		
--							
35			180.5	189.0			
36	199.4						
37						183.7	
38					191.8		
39		190.4					
--							
42			198.3	204.1			
43							198.7
44						199.0	
45	215.0						
46					207.7		
--							
49		207.7					

Table No. II, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall   Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
--							
52							215.6
53			218.1			213.8	
--							
58	228.9						
59							
60		218.1					
61							
62							221.5
63						222.1	
--							
68				230.5			
69	230.4						
70					228.9		
71							
72		225.1					
73				230.5			
74			229.5				227.5
75						228.6	
76					228.9		
--							
79	232.9		231.4				
--							
82			232.2				
83				233.2			
84							
85		229.7			232.5		231.8
86						232.9	
--							
91	233.6						
92							
93						234.1	234.1
94							
95		235.8					
96							
97			237.6	237.6			
98							
99	235.0						

102					237.9		

Table No. II, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall　　　　Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F

109			237.9	237.9			

112					237.9		

116				237.9			
117			237.9		237.9		

120							

Table No. II, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall — Retort Temperature--240° F.

Time	Can Numbers						
	VIII	IX	X	XI	XII	XIII	XIV
Min.	°F	°F	°F	°F	°F	°F	°F
0	65.3	63.1	64.3	64.5	65.1	65.4	64.3
1							
2					67.6		
3				72.1			
4							75.2
5	78.8						
-							
9			104.5				
10					98.2		
11		125.6					
12	110.3						
13							
14				126.5			
15					131.4		
--							
18	143.6				141.8		
19			146.3				
20							152.6
21		149.4					
22							
23						174.7	
--							
28							175.6
29							
30	192.2		199.0	186.4	185.0		
--							
33		187.3					
34						204.1	
35			205.7	198.7			
36					198.3		
37							
38		198.3					203.0
39							
40	207.7			208.4		212.4	
--							
44							213.4
45							
46	212.4		224.2				
47					217.1		

Table No. II, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall　　　　Retort Temperature--240° F.

Time	Can Numbers						
	VIII	IX	X	XI	XII	XIII	XIV
Min.	°F	°F	°F	°F	°F	°F	°F
48							
49		214.5					
--							
52							227.1
--							
55	225.1						
56				228.6	226.0		
57			232.5				
58							227.8
59							
60		226.8					
61						232.5	
62				232.9			
--							
65					231.8		
66							
67							232.9
68			233.2				
69							
70	231.4					236.5	
71							
72		233.2					
73					234.5		
74				236.1			235.4
--							
78						236.9	
--							
83	235.8						236.5
--							
86			237.6				
87		236.1					
88							
89	232.5				237.6		
--							
92				236.5		237.6	
--							
95	236.1						237.6
--							
101					237.9		

Table No. II, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--1 lb. Tall   Retort Temperature--240° F.

Time	Can Numbers						
	VIII	IX	X	XI	XII	XIII	XIV
Min.	°F	°F	°F	°F	°F	°F	°F
102							
103			237.9				

106		237.2					

109				237.6			
110			238.6				

114		238.3					
115				238.3			

120							

Table No. III

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
0	64.5	65.4	64.9	64.2	64.9	65.3	64.4
-							
3	69.4						67.5
4		73.9					
-							
7					73.4	75.2	
8				77.9			
9		86.9	76.1				
10	82.4						
11							81.0
12							
13		99.1					
14	93.7						
15					90.5	95.0	
--							
18							101.8
--							
21			105.8		104.9	109.9	
22				112.1			
23							
24							118.9
--							
28					120.7		
29						130.6	
30							
31				136.0			
32			134.2				
33							141.4
34							
35	148.1	152.2			143.6		
--							
39						152.2	
--							
42				156.7			
43			154.8				163.0
--							
46				162.5			
47	175.1	176.5	162.5				

Table No. III

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
--							
51					167.0		
52						177.4	
--							
55							183.0
56							
57				181.0			
58			181.0				
59							
60					180.5		
61						189.3	
--							
64		189.7					195.0
65	198.3						
--							
69					192.2	199.4	
--							
72		206.6					202.6
--							
75	206.6				198.0	204.8	
--							
78			204.1	205.3			
79							209.3
80							
81					204.5	212.0	
--							
85							215.2
86							
87					208.9	216.0	
88		218.5					
89	218.1						
90							
91							218.5
--							
95			216.3	216.3			
--							
99					216.3	221.7	

102							222.8

Table No. III

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No $2\frac{1}{2}$ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
103		226.0					
104							
105	226.0				220.1		
106							
107						224.2	
108							
109							225.5
110				222.8			
111			222.4				

120					224.6	227.8	
121							
122				226.8			
123		230.5	227.1				
124	230.9						228.9

130					227.5		
131							
132						230.9	
133							
134							231.4
135							
136				230.0			
137			229.6				

142					228.9	231.8	

145							231.8

153					230.9		
154						232.5	

157				234.5			231.8
158		234.1	233.2				
159	236.1						

166					232.9	233.6	

169				235.0			

Table No. III

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
170			235.0				

175		235.8					
176							
177	236.8						

182				236.1			
183			236.1				

188		237.2					
189	237.2						

211					234.1		
212						235.0	

215							234.5

227			237.2				
228				237.6			

Table No. IV, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
0	65.1	65.3	64.9	65.3	64.4	64.9	64.9
1		66.2					
2					68.5		
3	68.5						
4							68.5
5						69.8	
6				69.4			
7							
8			78.4		73.0		
9	82.0	81.9					
--							
14					81.1	86.0	92.3
15		100.0	95.5				
16				90.5			
--							
20	113.0						
21							
22						115.3	
23							118.9
24							
25			120.7		109.9		
26		129.2		117.0			
--							
29	136.0						
30							
31							142.9
--							
34			145.4	141.0	131.0	143.6	
35		152.6					
--							
38	156.2						
39						157.1	
40							163.8
41							
42					149.7		
43							
44				164.5			
45	169.5	176.5	168.0				
--							

Table No. IV, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
50			176.5				
51		186.8				182.1	186.5
52				181.4			
53	182.5				171.1		
--							
57						191.3	
58			188.2				
59		198.0					
60	193				182.8		199.0
--							
64			195.5	199.8			
65		205.3					
--							
69	203.7						
70							
71							211.6
72					199.0	209.8	
73							
74			207.3				
75		215.2					
--							
78				215.6			
79			212.4				
80		218.9					
--							
84	209.3						
85							
86				221.7	213.8	222.1	
--							
90	220.1						
91						225.1	224.6
92							
93					218.1		
94							
95			220.6	224.6			
96		227.5					
--							
99	225.0						
100						226.4	

Table No. IV, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
101							
102							229.3
103					221.7		
104							
105		220.0					
106				228.9			
107			224.3				
108							231.4
109	229.5						
110							
111						231.8	
112				231.8			
113							
114					227.1		
115		233.3	227.5				
116							
117						232.9	
118	231.8						
119							
120					229.0		
121							233.6
122							
123			229.3				
124		235.4		234.5			

129	233.6						
130						232.9	

133					231.8		235.0
134			231.8				
135							
136		235.8		234.5			
137	234.1						

142							236.8
143			232.9				
144		236.1					
145					233.6		

Table No. IV, Section I

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
152							237.7
153	235.4						

159	236.1		234.5				
160		237.6					
161							237.9

164			235.0				
165		237.2					
166							
167			235.0				237.9
168							
169		237.6					

174	235.8						

180							

Table No. IV, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. $2\frac{1}{2}$ Retort Temperature--240° F.

Time	Can Numbers					
	VIII	IX	X	XI	XII	XIII
Min.	°F	°F	°F	°F	°F	°F
0	65.4	64.5	64.7	65.0	63.9	64.5
--						
8	75.7					
9					96.0	81.5
10		74.8	86.0	100.0		
--						
17	94.1			122.5		100.9
18		98.6			118.0	
19			112.1			
--						
26						125.6
27	128.8					
28		127.9		148.1		
29					147.2	
30			139.1			
--						
35	142.5					161.3
36						
37		151.3				
--						
40				175.1		
41					174.2	
42			168.4			
43						
44	171.1					
45						
46		173.1				
--						
49			181.8	189.7		181.4
50					198.4	
--						
57	191.8					
58						
59				202.6		
60		195.8			204.0	198.3
61						
62			201.7			
63						
64	199.8					

Table No. IV, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers					
	VIII	IX	X	XI	XII	XIII
Min.	°F	°F	°F	°F	°F	°F
65						
66		204.1				
--						
70				212.0	212.0	
71						
72			211.6			
73						
74						212.7
75	211.6			216.0		
76					217.8	
77						
78		215.6	216.3			
--						
87						221.4
88				223.9		
89					224.2	
90			224.6			
--						
95	223.5					
--						
98		226.8				
99				227.8		
100					228.2	228.2
101			227.8			

106	228.9			230.5	230.5	
107						228.6
108			230.9			
109		230.5				
110						
111	231.3					
112						
113		232.5				

121				232.9		
122					232.9	
123			232.9			
124						
125	232.9					

Table No. IV, Section II

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers					
	VIII	IX	X	XI	XII	XIII
Min.	°F	°F	°F	°F	°F	°F
126						
127		234.1				233.6

130				234.1		
131					235.0	
132						
133			232.9			

136	235.0			234.5		235.4
137		235.0			235.8	
138						
139			234.5			

147		236.8				
148						
149				236.1	235.8	
150						
151			236.1			

155	237.7					
156						
157		237.7				
158						
159				236.1		
160					236.1	
161						
162			236.1			

165	237.9					
166		237.9		236.9	236.9	
167						
168			236.9			
169						
170	237.9					
171		237.9				

Table No. V

TEMPERATURES IN STATIONARY CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers			Time	Can Numbers		
	I	II	III		I	II	III
Min.	°F	°F	°F	Min.	°F	°F	°F
0	65.6	64.4	65.5	63	198.3		
-				64			
7	83.3		76.8	65		199.0	
8		86.0		--			
-				68	202.1		
12	95.7		91.0	69		202.6	
13		98.6		70			201.7
14				--			
15	103.0			73			204.8
16		106.3		--			
17			103.1	79	211.3		
--				80		211.5	
20			111.2	--			
21				83	213.8		
22	123.8			84		213.8	
23				85			213.5
24		128.3		--			
--				88			215.2
29	142.5		136.4	--			
30				91	217.8		
31		145.9		92		218.1	
--				--			
36			150.8	96			219.2
37				97			
38	161.2			98	221.7		
39				99		222.0	
40		163.4		---			
--				103			222.8
43	169.5			---			
44			168.0	110	225.5		
45		172.4		111		226.0	
--				---			
49			176.5	115			227.1
--				---			
54	187.7			124	228.2		
55				125		229.0	
56		189.3		---			
--				129			229.6
60			192.2	---			

Table No. V

TEMPERATURES IN STATIONARY CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers		
	I	II	III
Min.	°F	°F	°F
134	230.0		
135		230.0	

139		230.0	

145	231.4		
146		231.8	

150			232.5

180	235.0		
181		235.8	

185			236.1

Table No. VI

TEMPERATURES IN AGITATED CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
0	64.9	64.9	64.4	65.5
-				
4				70.7
5			77.9	
6		77.9		
7				
8	83.8			
-				
14		89.6		
15				
16	112.6			
17				
18				90.0
19				
20			132.4	
--				
23		113.0		
24	155.5			
--				
30		134.2		
31				
32			205.7	
--				
40		166.1		175.1
41				
42			211.2	
43	203.7			
--				
46				185.0
47				
48			218.5	
49		186.8		
--				
53				194.7
--				
56	218.9			
--				
59			225.0	
--				

Table No. VI

TEMPERATURES IN AGITATED CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
62		206.2		
63				208.0
--				
68			233.6	
69				
70	226.8			
--				
73				217.0
--				
77		218.5		
78			232.1	
--				
82				220.6
83				
84	231.8		232.5	
--				
88				224.6
--				
94		223.8		
--				
97	234.0			
--				
104		230.5		

107	235.0			

114		230.5		
115	236.0			

121		232.2		

135	235.8			

142	236.1			

148		233.6		

Table No. VII

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers				
	I	II	III	IV	V
Min.	°F	°F	°F	°F	°F
0	64.4	64.3	64.5	65.4	
1					
2	67.6				
3			69.4		
4	71.6				
5				79.3	
6					89.6
7					
8		81.5		90.5	
9			83.3		
10	86.5				
11					
12		92.8			94.5
13			94.6		
14	98.2				
--					
21				127.0	
--					
24		125.6			
25			126.5		
26	132.8				
27					123.4
--					
30				144.0	
--					
33		148.6			
34			149.7		
35	158.0				141.8
--					
39				164.1	
--					
42		167.5			
43			169.2		
44	178.9				
--					
47					167.5
--					
50				182.8	
--					

Table No. VII

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. $2\frac{1}{2}$ Retort Temperature--250° F.

Time	Can Numbers				
	I	II	III	IV	V
Min.	°F	°F	°F	°F	°F
53		188.6			
54	196.7		189.0		
55					183.7
--					
61				197.6	194.4
--					
64		203.0			
65			203.4		
66	212.0			203.4	
--					
69		208.0			
70			208.4	209.3	
71		216.3			
72		212.4			
73					
74			212.7		212.4
75	220.1				
--					
83				220.1	
84					220.6
85					
86		224.3			
87			224.3		
88	229.3				
--					
93				227.5	226.8
--					
96		230.9			
97			230.9		
98	235.8				
99				229.3	
--					
102		232.2			232.5
103			232.5		
104	236.1				

114		237.2			
115			237.6		
116	240.0				241.5

Table No. VII

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers				
	I	II	III	IV	V
Min.	°F	°F	°F	°F	°F

126					245.8

131				240.4	

134		242.3			
135			243.0		
136	244.4				

139					248.0

145				243.0	

148		244.4			
149			244.4		
150	244.9				247.7

154				244.0	

157		244.9			
158			245.3	244.4	
159	246.6				
160					
161		245.3			
162			245.3		
163	246.6				

Table No. VIII

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
0	64.3	65.5	64.7	65.2	64.9	64.7	64.9
1							
2			65.8				
3		72.0		67.6	67.6	67.6	
-							
6	76.6						
-							
12							97.7
13		102.2					
14			90.0		91.4		
--							
17	108.7		101.3				
18							
19						90.0	
20							124.5
21							
22				111.2	113.0		
--							
26		143.2				106.3	
27							
28	135.5		131.0				
--							
31				138.2			
32					138.2		160.2
--							
36		164.5					
37							
38						149.4	
39							
40							181.0
--							
46							191.7
47			176.5			172.4	
48							
49	188.6						
50				184.1			
51							
52					184.1		
53						184.1	

Table No. VIII

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
54			189.0				
55				191.3			
56		197.6					
57	200.8				193.3		
58							
59							214.7
--							
62		205.7					
--							
66	212.0		207.0			207.0	
67							
68				209.8	209.3		
69							223.5
70		215.2					
--							
74			216.3				
75							
76						218.1	
77				219.7	218.8		
78							229.6
--							
82			222.0				
83							
84				224.2	224.2		
85						224.6	
86							
87							236.1
88	228.2						
--							
94		233.6				231.4	
--							
99	237.6						
100							243.3
101							

106		238.3					
107	240.8						
108							
109						238.3	

Table No. VIII

TEMPERATURES IN AGITATED CANS OF SALMON

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers						
	I	II	III	IV	V	VI	VII
Min.	°F	°F	°F	°F	°F	°F	°F
110							
111		238.3					247.2

115			239.9				
116							
117				241.5			
118					239.9		
119						241.9	

124							248.5

127			241.1				
128				241.5	241.2		

132						244.9	

135							248.9
136	246.6						

140		246.6					
141			243.7				
142						245.8	
143				244.0	244.0		

150	248.5						

154		248.5					

174							250.5
175			246.6				
176							
177				246.6	246.6		

182						247.6	

Table No. IX

TEMPERATURES IN STATIONARY CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--240° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
0	65.0	64.7	64.9	65.0
1				
2	67.6			
3		69.8		68.0
4			72.5	
--				
7	77.9			
8		80.6		71.6
9			83.8	
--				
12	90.0			79.7
13		93.2		
14			96.0	
15				
16	99.0			
17		103.1		85.6
18			107.6	
--				
22				102.7
--				
25	124.9			
26		128.3		113.5
27			133.7	
--				
35	149.4			138.2
36		153.5		
37			155.8	
--				
45	171.0			161.6
46		173.5		
47			174.7	
--				
55				182.8
--				
58	192.2			
59		192.9		
60			195.0	
--				
68	203.7			203.7

Table No. IX

TEMPERATURES IN STATIONARY CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
69		204.4		
70			207.0	
--				
78				216.2
79				
80	215.1			
81		216.7		
82			217.4	
--				
90	222.8			
91		223.5		
92			225.1	
--				
100	227.8			233.6
101		228.6		
102			229.3	
103				
104	229.6			
105		230.9		
106			231.8	

110				237.2

114				237.2

119	235.8			
120		236.8		
121			235.8	

128	238.6			
129		239.0		241.5
130			239.5	

138				243.0

142	241.1			
143		241.9		
144			241.9	

Table No. IX

TEMPERATURES IN STATIONARY CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F

152				244.9

159	243.7			
160		244.0		
161			244.0	

170				246.9

182	247.3			
183		247.3		
184			247.9	

192				249.0

Table No. X

TEMPERATURES IN AGITATED CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
0	65.3	65.0	64.9	65.2
1				65.8
--				
5	137.1		101.3	
--				
8				102.2
9				
10	137.8		122.5	
--				
16				120.2
--				
19	208.4		197.6	
--				
22				141.8
23			221.0	
24	231.8			
--				
27	242.6			
28				
29		244.0		
30				
31			232.2	
--				
37				181.4
--				
40	245.8			
41				
42		246.6	242.2	
--				
46				199.0
--				
49	247.3			
50		247.3	245.8	
51				
52				211.7
--				
56	248.0			
57				
58		248.0	247.8	

Table No. X

TEMPERATURES IN AGITATED CANS OF SALMON BY-PRODUCTS

Can Size--No. 2½ Retort Temperature--250° F.

Time	Can Numbers			
	I	II	III	IV
Min.	°F	°F	°F	°F
--				
67	248.0	248.0	247.3	225.5
--				
76				231.4
--				
88	249.8		249.8	
89		249.8		
90				
91				233.6
--				
98				241.3
--				
140				247.6

Table No. XI

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 10   Retort Temperature--250° F.

Time	Can Numbers		
	I	II	III
Min.	°F	°F	°F
0	65.0	64.6	64.6
12	73.0		
18		77.0	77.9
19	79.3		
25		84.7	85.6
31	93.2		
37		98.2	99.5
40	102.2		
46		108.3	109.4
47	109.9		
53		116.6	118.9
58	124.5		
64		129.7	132.8
70	139.1		
76		144.0	147.7
77			
78	145.0		
84		150.8	154.0
96	163.4		
102		167.0	171.0
109	174.7		
115		178.2	181.4
125	187.7		
132		190.0	193.3
138	192.2		
144		197.2	200.1
159	207.7		
165		207.7	211.6
168	211.3		
175		213.1	216.7
184	218.1		
191		218.1	221.4
198	223.2		
204		222.5	225.5
215	227.5		
222		226.4	229.0
232	231.0		
238		230.9	234.0
258	236.1		
265		236.1	237.2
282	237.9		

Table No. XI

TEMPERATURES IN STATIONARY CANS OF SALMON

Can Size--No. 10 Retort Temperature--250° F.

Time	Can Numbers			Time	Can Numbers		
	I	II	III		I	II	III
Min.	°F	°F	°F	Min.	°F	°F	°F
288		238.3	238.6	---			
---				324	243.0	243.0	
318	240.8			---			

Table No. XII

COPPER CONSTANTAN THERMOCOUPLES, COLD JUNCTION 0° C.

(Leeds & Northrup Co.)

Deg. C.	0	10	20	30	40	50	60
			Millivolts				
0	.0	.40	.80	1.20	1.61	2.03	2.46
1	.04	.44	.84	1.24	1.65	2.07	2.50
2	.08	.48	.88	1.28	1.69	2.12	2.55
3	.12	.52	.92	1.32	1.74	2.16	2.59
4	.16	.56	.96	1.36	1.78	2.20	2.63
5	.20	.[illegible]0	1.00	1.40	1.82	2.24	2.67
6	.24	.64	1.04	1.45	1.86	2.29	2.72
7	.28	.68	1.08	1.49	1.90	2.33	2.76
8	.32	.72	1.12	1.53	1.95	2.37	2.80
9	.36	.76	1.16	1.57	1.99	2.42	2.85
10	.40	.80	1.20	1.61	2.03	2.46	2.89

Deg. C.	70	80	90	100	110	120	130
			Millivolts				
0	2.89	3.33	3.78	4.24	4.71	5.17	5.63
1	2.93	3.37	3.83	4.29	4.75	5.21	5.67
2	2.98	3.42	3.87	4.33	4.80	5.26	5.72
3	3.02	3.46	3.92	4.38	4.84	5.31	5.77
4	3.07	3.51	3.97	4.43	4.89	5.35	5.82
5	3.11	3.55	4.01	4.47	4.94	5.40	5.86
6	3.15	3.60	4.06	4.52	4.98	5.44	5.91
7	3.20	3.64	4.10	4.57	5.03	5.49	5.96
8	3.24	3.69	4.15	4.61	5.08	5.54	6.00
9	3.29	3.73	4.19	4.66	5.12	5.58	6.05
10	3.33	3.78	4.24	4.71	5.17	5.62	6.10