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Some internal physical conditions in glass containers of food during thermal treatment

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SOME INTERNAL PHYSICAL CONDITIONS IN GLASS CONTAINERS OF FOOD DURING THERMAL TREATMENT

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I. INTRODUCTION

Commercial preservation of food materials is done almost entirely in tin containers because of the ease of handling in rapid production methods and the reduction of the breakage factor to a minimum. Home preservers and small scale producers of preserved foods do not have the factor of speed and breakage to contend with and in using glass have the advantages of the reuse value and the appearance of the product itself.

The glass jarsused in preserving fruits, vegetables and meats are of many sizes, shapes and designs with a wide variety of closure-types. The glass cover and jar with rubber ring and wire bails of the "lightning" type are used extensively.

Preliminary data indicate the possibility that glass jars equipped with wire clamps may be processed (sterilized) while closed (clamps down). This is contrary to present custom, but if possible will effect a considerable saving of time, greater convenience and possible superior quality in the resulting food.

A review of the literature shows a minimum of research on glass containers and especially on the method of processing metal clamped, glass covered jars.

From extension specialists in home preservation has come word of various instances of processing glass jars with covers sealed tightly (clamps down) with good success.

The object of this research project is to ascertain the pressure conditions within a jar of food during processing with a view of determining the safety and practicability of subjecting the fully sealed jar to the final process or heat treatment. Of course, the usual procedure followed at present is to only partially seal the jar, the seal being completed after processing.

II. VACUUM

Experimental

A good partial vacuum in the sealed jar is of primary importance in the canning of food. Vacuum is generally expressed in "inches of mercury" and may be described as the absence of "normal pressure." Normal pressure is that due to the weight of the air enveloping the earth. This is called atmospheric pressure and at sea level is approximately fifteen pounds per square inch.

If a jar is closed at room temperature, the air within exerts the same pressure outwards as the atmosphere without exerts on the container. If a part of the air in the jar is removed and the jar is then closed, the remaining air exerts less pressure outwards than the atmosphere exerts upon the outside of the jar, and it is said that a "partial vacuum exists in the container." Atmospheric pressure, at sea level, is sufficient to support a column of mercury thirty inches high, having a cross section of one square inch. If the air remaining in the "partial vacuum" supports a column of mercury to a height of twenty inches, then the difference between the height of the two columns, ten inches, represents the "vacuum." This vacuum is what is meant whenever the word is used in this thesis and in canned food literature, in general.

Vacuum in the glass covered type of jar, fitted with a wire bail, is produced by either heating the food before it is placed in the jar or by heating the product in the container. The application of heat to the material being preserved causes them to expand. If the jar is sealed tightly, permitting no air to enter, the contents on cooling will contract, producing a partial vacuum in the container.

The two important reasons for obtaining a vacuum in glass covered jars are : (1) To keep the cover on and prevent loss of liquid and recontamination by micro-organisms and (2) To restrict the growth of some micro-organisms.

Tight clamping of the wire bails or clamps over the tops of the glass covers of the jars does not in itself prevent liquid from escaping during processing. That is, venting of gas occurs regardless of whether or not the bails are loose or tight. Nevertheless, pressures in excess of atmospheric are generated within the jars during heating and this pressure forces out a part of the gases remaining in the headspace.

This pressure also prevents the entrance of air that might contain contaminating organisms. The function of the wire bails is to direct the glass cover down in close contact with the rubber ring to a correct setting while the vacuum is forming. The vacuum forms as soon as the jar cools, immediately following the process.

Practically all spoilage in preserved foods is due to growth of yeasts, molds and bacteria. Vacuum is important in this respect in that it inhibits the growth of some molds, and aerobic bacteria (1), (2). Anaerobic bacteria are not restricted by the presence of a vacuum, but are largely destroyed or inactivated by the thermal treatment. It can be seen that in developing the most efficient method of precessing foods, production of a vacuum is a most important requisite.

Obviously, the normal method of determining vacuum, piercing the cover with a pointed gauge graduated for the purpose, cannot be carried out on glass covered jars. Consequently two methods of determining vacuums in glass covered jars were utilized.

Method of Determining Vacuum

M.S.C. Method

A desiccator is connected with vacuum tubing to a water pump. The connections are tight so that a vacuum of 27 or 28 inches can be obtained. After loosening the bail, the jar is immersed in a large glass jar of water. Both jar and container are then placed in the desiccator and the aspirator allowed to slowly exhaust the air from the system. When the vacuum inside the desiccator becomes higher than that in the jar of food, the glass cover will lift, breaking the vacuum and allowing bubbles to escape from the jar. The vacuum gauge, which is set in the system between the faucet and the desiccator, is read at this time. (See Plate I.) The vacuum reading thus obtained shows

Plate I. Apparatus for determining vacuum
by the M.S.C. Method

that the vacuum present in the jar of food was slightly lower than the figure obtained. The slight resistance of adhesion between rubber rings and jar is negligible in most cases of freshly sealed jars. In this work most jars were examined within a day after canning.

Gray Method

The second method eliminates the error of adhesion between rubber ring and cover. (3)

The jar is weighed after processing. This weight included the complete container and contents. The jar is then immersed in water in an inverted position and the seal broken, permitting the headspace to fill with water in proportion to the vacuum in the headspace. Still holding the jar inverted, the water levels inside and outside the jar are made the same, the cap is replaced, the clamp tightened down, and the jar is then removed from the water, wiped off and reweighed. The difference in weight between the second and first weighing gives the amount of water which was sucked in. The lid is then removed and the jar filled completely with water, including the space under the glass cover. This weight minus the first weight gives the volume of headspace, and from the weight of water sucked in, the vacuum can be determined.

An example:

a.	Wt. of jar and contents after processing	980 grams
b.	Wt. after opening under water	1030 grams
c.	Gain in weight (b-a)	50 grams(cc.)
d.	Wt. of jar completely full	1050 grams
e.	Original headspace volume (d-a)	70 grams(cc.)
f.	Vacuum $\frac{b-a}{d-a} \times 30$	21.4 inches

For ease in differentiation, the determination of vacuums by placing jar and contents in a desiccator and reading of the gauge when vacuum has been neutralized, will be designated as the M.S.C. Method. The process of determining vacuums by weight differences will be called the Gray Method.

Pint jars, with new bails and rubber rings, were filled with water and processed in a bath of boiling water. A and B are duplicates on each processing time. Results are shown in Table 1.

The object of this experiment was to compare the two methods of determining vacuum in glass jars as to practicability and accuracy.

Relative Accuracy of the M. S. C. and Gray Methods of Determining Vacuum in Glass Jars of Food

The data in Table 1 are representative in showing that reasonably good checks can be obtained by either method. Similarly where the two methods are compared with each other, the results are likewise in very satisfactory agreement. The Gray method is the more rapid. Both are entirely satisfactory for determining the vacuum in sealed glass jars. In jars which have been sealed a long time, and where the rubber ring adheres tightly to the top of the jar and lid, the M. S. C. method gives greater vacuums than actually exist. This is because of the necessity of overcoming this sticking of the rubber ring to the glass. However, in most cases, even in old packs, the method gives quite satisfactory results on the whole, though it may be of no value on occasional jars.

Table 1 Comparison of M.S.C. and Hazel Atlas Methods of Determining Vacuum on Glass Jars

Four Jars Identically Filled and Processed

M. S. C. Method

Vacuum, Inches of Hg.

A	B
25.0	25.3
25.5	25.8
26.0	26.0
22.0	22.4
23.8	23.4
26.2	26.5
25.0	25.9
25.0	25.3
26.6	25.5
26.3	26.0
23.0	23.9
25.1	25.3
25.9	26.0
24.1	26.4
28.2	28.4
28.7	28.3
28.0	29.1
27.8	28.2

Gray Method

Vacuum, inches of Hg.

A	B
25.2	25.5
26.1	26.7
26.7	25.9
20.4	24.3
25.8	25.2
26.7	27.9
26.7	25.8
24.9	25.5
25.8	27.0
26.7	26.4
24.0	24.0
24.0	24.9
24.9	25.8
24.9	24.7
28.2	28.9
28.7	28.5
29.2	28.3
28.9	27.6

Comparisons of Vacuums Obtained in Pint Glass Jars Filled and Processed at Several Temperatures with Different Headspace

Both the M.S.C. and Gray methods of determining vacuum were used. The object of this experiment was to determine how the amount of headspace in the container and temperature of filling affected the vacuum obtained in the sealed, processed and cooled jars.

Rubber rings and wire bails were not reused in any case. Water was used to fill the jars as a basis on which results could be checked with food products. The time of processing in all tables is 15, 20 and 25 minutes because pint jars containing water, if processed correctly, reach their maximum temperature in 20 minutes. Duplicates were made in each timing period, by both methods of determining vacuum. Averages of duplicate vacuum determinations are given in Tables 2 to 5, which are largely self-explanatory.

Discussion of Tables 2 to 5

In processing pint glass jars of water, vacuums of 20 inches or more may be expected regardless of whether the jars were partially or fully sealed during the processing period of 15 to 60 minutes. These are higher vacuums than are normally found in tin cans of food. Nearly maximum vacuums were obtained by processing the pint jars of water at 212°F. for as little as 15 minutes. Maximum figures of over 28 inches of vacuum were obtained by processing at 240°F. in the pressure cooker. Temperature of filling or headspace had little influence.

In general, the jars fully sealed before the process, yielded

Table 2 Vacuums Produced in Pint Glass Jars. Processed at 212°F. With Jars Completely Filled With Water (Headspace 65 cc.*) at Variable Filling Temperatures.

Process Time **	Condition of Seal	Filling Temp. °F.	Vacuum M.S.C. in. Hg.	Vacuum in. Hg.	No. jars	Cpvers Broken
15	Partial	70	25.2	25.3	4	0
20	Partial	70	26.1	26.2	4	1
25	Partial	70	26.0	26.4	4	0
15	Fully	70	18.3	20.7	4	0
20	Fully	70	20.0	21.6	4	0
25	Fully	70	19.5	22.2	4	1
15	Partial	150	24.6	25.9	4	0
20	Partial	150	24.2	26.9	4	0
25	Partial	150	25.8	26.7	4	0
15	Fully	150	20.3	21.0	4	0
20	Fully	150	21.0	20.7	4	0
25	Fully	150	20.8	24.0	4	0
15	Partial	212	26.3	26.6	4	0
20	Paftial	212	25.5	28.0	4	0
25	Partial	212	25.7	28.1	4	0
15	Fully	212	22.2	22.3	4	0
20	Fully	212	22.4	22.8	4	0
25	Fully	212	21.8	23.5	4	0

* 65 cc. represents the unfilled space under the dome of the cover.

** Time began when bath was at 212° F.

Table 3. Vacuums Produced in Pint Jars Containing Water Processed at 212°F. with 69 cc. Headspace* at Variable Filling Temperatures.

Process Time	Condition of Seal	Filling Temp. Deg.F.	Vacuum M.S.C. Method	Vacuum Gray Method	No. of Jars	No. of Broken Covers
15	Partial	70	23.6	25.5	4	0
20	Partial	70	25.4	26.2	4	0
25	Partial	70	26.3	27.3	4	0
15	Sealed	70	19.9	21.0	4	0
20	Sealed	70	20.8	21.9	4	0
25	Sealed	70	22.2	21.4	4	0
15	Partial	150	24.9	25.9	4	0
20	Partial	150	26.0	27.6	4	1
25	Partial	150	26.2	26.6	4	0
15	Sealed	150	21.5	21.0	4	0
20	Sealed	150	21.5	20.7	4	0
25	Sealed	150	20.7	24.6	4	0
15	Partial	212	25.9	26.4	4	1
20	Partial	212	26.7	28.6	4	0
25	Partial	212	26.0	27.4	4	0
15	Sealed	212	20.7	25.8	4	0
20	Sealed	212	22.5	22.9	4	0
25	Sealed	212	22.4	21.7	4	0

* Headspace 5% greater than in Table 3

Table 4 Vacuums Produced in Pint Jars Containing Water Processed at 212° F. with 72 cc. Headspace* at Variable Filling Temperatures

Process Time	Condition of Seal	Filling Temp. Deg. F.	Vacuum in Inches of Hgl M.S.C. Method	Gray Method	Nol Jars	No. of Broken Covers
15	Partial	70	23.4	24.0	4	0
20	Partial	70	24.6	24.7	4	0
25	Partial	70	22.5	25.0	4	0
15	Sealed	70	17.8	19.9	4	0
20	Sealed	70	17.2	20.0	4	0
25	Sealed	70	17.2	20.8	4	0
15	Partial	150	25.2	24.4	4	0
20	Partial	150	25.8	25.2	4	0
25	Partial	150	25.9	25.3	4	0
15	Sealed	150	23.2	20.8	4	0
20	Sealed	150	19.2	19.5	4	0
25	Sealed	150	19.1	20.7	4	0
15	Partial	212	23.6	25.7	4	0
20	Partial	212	25.2	24.8	4	0
25	Partial	212	24.4	25.6	4	0
15	Sealed	212	21.1	18.7	4	0
20	Sealed	212	22.6	25.0	4	0
25	Sealed	212	21.3	21.2	4	0

* Headspace 10% greater than in Table 3

Table 5 Vacuums Produced in Pint Jars Containing Water Processed at 240°F. in Pressure Cooker* with 65 cc. Headspace (Full Jar) at Variable Filling Temperatures

Process Time	Condition of Seal	Filling Temp. Deg. F.	Vacuum in Inches of Hg. M.S.C.Method	Gray Method	No. of Jars	No. of Covers Broken
20	Partial	70	27.0	27.1	4	0
40	Partial	70	27.5	28.2	4	0
60	Partial	70	28.3	28.8	4	0
20	Sealed	70	26.0	26.3	4	0
40	Sealed	70	27.9	26.4	4	0
60	Sealed	70	28.0	25.9	4	0
20	Partial	150	28.3	28.5	4	0
40	Partial	150	28.5	28.6	4	0
60	Partial	150	27.8	29.1	4	0
20	Sealed	150	26.7	25.6	4	0
40	Sealed	150	27.3	28.3	4	0
60	Sealed	150	27.2	25.0	4	0
20	Partial	212	28.1	27.0	4	1**
40	Partial	212	28.0	28.2	4	0
60	Partial	212	28.6	28.7	4	0
20	Sealed	212	27.7	28.5	4	0
40	Sealed	212	26.7	28.9	4	0
60	Sealed	212	28.0	27.1	4	0

* Pressure released immediately following the process.

** Cover cracked approximately 1 minute after completing the seal.

slightly lower vacuums than the partially sealed jars, though this difference rarely exceeded 4 to 5 inches. Naturally, the differences were less as a perfect vacuum was approached.

Temperature of filling had little effect on final vacuum, though the relatively long 15-60 minute processes tended to equalize the temperatures attained by the jar contents. In fact, pint jars processed in this manner usually reached their maximum temperature (212° F.) after 15-20 minutes.

A comparison of headspaces in Tables 2, 3 and 4 show no significant effects of headspace on the resulting vacuums. At least this statement holds for headspaces of 65 to 72 cc.

There was no jar breakage in any experiment and only 5 cracked covers out of the 288 jars used. Four of these broken covers were from partially sealed jars and only one from the fully sealed jars. These data indicate that there is no greater danger of breakage from fully sealed than from partially sealed jars during the process.

Some of the jars were processed in the pressure cooker at 240°F. There was no breakage at all during processing, the one cover which cracked did so after tightening the bail while cooling.

Effect on Vacuum of Variable Filling and Processing Temperatures Where a Constant (Equalized) Headspace is Maintained

In the previous experiments, headspace was considered as the space from the overflow or uppermost rim of the jar to the surface of the liquid contained in the jar. Also, no allowance was made for the expansion of the liquid at the different filling temperatures. In this study headspace under the dome of the cover and adjustment to an equalized headspace for different filling temperatures were taken into consideration.

All headspaces are figured at 70° F. and the relative expansion of water at 150° F. and 212° F., was adjusted so that at any given temperatures the headspaces would be the same. Thus the temperature of filling would have no effect on the headspace of the jar.

The weight of the water held under the dome of the cover was found to average 35 grams, ie. the headspace of this under-the-cover volume was 35 cc. for pint jars.

In home canning, the jars are sometimes filled to overflowing with liquid and this leaves no headspace except [illegible] under the cover. Thus, jars filled at lower temperatures after processing and subsequent cooling, will have less headspace than other jars filled at higher temperatures. Therefore, a jar filled at 212° F. sealed, processed and cooled to 70° F. will have more headspace than another jar filled at 70° F. and cooled to the same temperature after processing. As all headspaces, to follow, are calculated at 70° F., the headspace of the jars filled at this temperature will be 54 cc. This will allow for the relative volume of water at 212° F., to give a headspace of 35 cc. The headspace at 150° F. will be 44 cc.

The next group will be 11 cc. larger than the original or 65 cc. in all at 70° F., 55 cc. at 150° F., and 46 cc. at 212° F.

Thus runs were made using adjusted headspaces of 54, 65, 80 and 96 cc. all measured at 70° F. and allowance made for expansion at higher temperatures.

Methods

A simplified method of getting accurate headspaces at these different temperatures is based on Archimedes principle of physics, "A floating body must displace its own weight of the liquid in which it floats."

Wooden blocks, heated to 250° F. in "boiled" oil and then allowed to soak 24 hours to prevent later absorption of water, were made so that they would displace the correct amount of liquid for each variance in temperature and headspace.

Table 6 shows the necessary calculation and weight for each block for each variance in temperature and headspace. Using these blocks in the succeeding experiments it was possible to secure the desired headspace in any jar.

Table 6 Determination of the Displacement Required to Obtain A Constant Headspace in Pint Glass Jars Filled at 70, 150 and 212° F.

Temp. Deg. F.	Relative Volume of Water	Cc. Change Due to Expansion of Water	Cc. of Headspace at Different Temps.	Wt. in Grams of Wooden Blocks
70	1.00198	------	54	19
150	1.01979	10	44	9
212	1.04343	19	35	--
70	1.00198	------	65	30
150	1.01979	10	55	20
212	1.04343	19	46	11
70	1.00198	------	80	45
150	1.01979	10	70	35
212	1.04343	19	61	26
70	1.00198	------	150	115
150	1.01979	10	140	105
212	1.04343	19	131	96

486 cc. of water at 70° F. fills the standard pint jar, not including dome of the cover. There is 35 cc. of headspace in the cover.

III. VENT LOSSES DURING PROCESSING

Because both methods of vacuum determination checked satisfactorily, only the M. S. C. method is used in the following experiments.

In each previous table it was noted that the fully sealed jars had higher final water levels than the partially sealed jars after the processing and cooling.

The calculations are made by weighing the jar, cover, rubber ring, and wire bail with varying headspaces with water at 70° F. This water, in the case of the jars to have an initial content temperature of 150 and 212° F., is poured out and water of the desired temperature is filled to the corresponding headspace.

The jars are weighed at 70 F., in the case of initial temperatures of 150 and 212° F., to have standardized conditions with the lowest initial temperature.

After the processing period is over, the jar cover, rubber ring, wire bail and contents are allowed to cool to 70° F. and then reweighed. The difference in weight is due to vent losses during the processing period. These data are presented in Tables 7 - 12.

Tables 7 - 9 show results on jars that had been processed at 10 pounds pressure and the pressure released rapidly; taking approximately 1 minute. Tables 10 - 12 show results on jars processed at 10 pounds pressure and the pressure released slowly. This is done by keeping the petcock closed and shutting off the

Table 7. Loss of Weight of Contents of Pint Glass Jars Filled at Varying Temperatures to Constant Headspace of 54 cc. and Processed at 240° F. (Pressure Released Rapidly)

Processing Time Minutes	Temp. Filling Deg. F.	Condition of Seal	No. of Jars	No. Broken	Vacuum Inches	Venting Loss Grams
20	70	Partial	2	0	26.4	72.9
40	70	Partial	2	0	27.2	101
60	70	Partial	2	0	28.3	103.7
20	70	Sealed	2	0	26.7	4.3
40	70	Sealed	2	0	25.9	3.0
60	70	Sealed	2	0	26.1	20.5
20	150	Partial	2	0	28.1	104
40	150	Partial	2	0	27.8	66.8
60	150	Partial	2	0	27.9	95.2
20	150	Sealed	2	0	26.5	1.5
40	150	Sealed	2	0	27.1	4.8
60	150	Sealed	2	0	26.0	8.6
20	212	Partial	2	0	27.6	74.0
40	212	Partial	2	0	28.2	137.5
60	212	Partial	2	1	27.9	83.1
20	212	Sealed	2	0	26.8	9.6
40	212	Sealed	2	0	27.4	15.2
60	212	Sealed	2	0	27.9	10.0

Table 8. Loss of Weight of Contents of Pint Jars Filled at Varying Temperatures to Constant Headspace of 65 cc. and Processed at 240°F. (Pressure Released Rapidly)

Processing Time Minutes	Temp.of Filling Deg.F.	Condition of Seal	No. of Jars	No. of Covers Broken	Vacuum Inches	Venting Loss Grams
20	70	Partial	2	0	27.7	53.2
40	70	Partial	2	0	27.5	83.3
60	70	Partial	2	0	27.9	96.6
20	70	Sealed	2	0	26.3	2.0
40	70	Sealed	2	0	26.7	2.5
60	70	Sealed	2	0	27.3	3.5
20	150	Partial	2	0	27.7	82.5
40	150	Partial	2	1	27.8	53.6
60	150	Partial	2	0	27.6	41.5
20	150	Sealed	2	0	26.3	2.1
40	150	Sealed	2	0	26.3	12.9
60	150	Sealed	2	0	26.6	3.6
20	212	Partial	2	0	28.2	57.8
40	212	Partial	2	0	28.0	131.0
60	212	Partial	2	0	28.4	81.8
20	212	Sealed	2	0	27.5	11.7
40	212	Sealed	2	0	22.8	6.9
60	212	Sealed	2	0	21.5	19.5

Table 9. Loss of Weight of Contents of Pint Jars Filled at Varying Temperatures to Constant Headspace of 150 cc. and Processed at 240° F. (Pressure Rapidly Released)

Processing Time Minutes	Temp.of Filling Deg.F.	Condition of Seal	No. of Jars	No. of Broken Covers	Vacuum Inches	Venting Loss Grams
20	70	Partial	2	0	28.0	7.3
40	70	Partial	2	0	27.6	18.3
60	70	Partial	2	1	28.3	22.4
20	70	Sealed	2	0	24.7	0.8
40	70	Sealed	2	0	27.1	0.9
60	70	Sealed	2	0	25.5	1.2
20	150	Partial	2	0	28.1	10.3
40	150	Partial	2	0	28.3	11.8
60	150	Partial	2	2	-	-
20	150	Sealed	2	0	25.7	6.8
40	150	Sealed	2	0	25.6	4.9
60	150	Sealed	2	0	25.9	5.7
20	212	Partial	2	0	27.8	32.4
40	212	Partial	2	0	27.2	25.9
60	212	Partial	2	0	27.9	19.1
20	212	Sealed	2	0	26.6	20.6
40	212	Sealed	2	0	26.0	6.3
60	212	Sealed	2	0	26.9	10.0

Table 10. Loss of Weight of Contents of Pint Jars Filled at Varying Temperatures to Constant Headspace of 54 cc. and Processed at 240° F. (Pressure Slowly Released)

Processing Time Minutes	Temp. of Filling Deg. F.	Condition of Seal	No. of Jars	No. of Covers Broken	Vacuum Inches	Vent Loss Grams
20	70	Partial	2	0	28.0	62.2
40	70	Partial	2	1	27.8	47.8
60	70	Partial	2	0	27.7	45.5
20	70	Sealed	2	1	24.0	14.1
40	70	Sealed	2	0	23.5	12.4
60	70	Sealed	2	0	24.4	10.9
20	150	Partial	2	0	27.8	43.2
40	150	Partial	2	0	28.0	42.6
60	150	Partial	2	0	27.9	34.0
20	150	Sealed	2	0	26.3	7.6
40	150	Sealed	2	0	27.2	10.8
60	150	Sealed	2	1	27.8	11.7
20	212	Partial	2	0	28.0	27.9
40	212	Partial	2	0	26.4	36.1
60	212	Partial	2	0	26.5	21.7
20	212	Sealed	2	0	26.7	9.7
40	212	Sealed	2	0	27.4	15.1
60	212	Sealed	2	0	27.4	5.8

Table 11. Loss of Weight of Contents of Pint Jars Filled at Varying Temperatures to Constant Headspace of 65 cc. and Processed at 240° F. (Pressure Slowly Released)

Processing Time Minutes	Temp. of Filling Deg. F.	Condition of Seal	No. of Jars	No. of Covers Broken	Vacuum Inches	Vent Loss Grams
20	70	Partial	2	0	27.9	28.9
40	70	Partial	2	0	28.3	35.3
60	70	Partial	2	0	27.5	35.4
20	70	Sealed	2	0	26.4	2.6
40	70	Sealed	2	0	25.1	2.5
60	70	Sealed	2	0	27.1	4.4
20	150	Partial	2	0	27.8	19.6
40	150	Partial	2	0	27.9	29.8
60	150	Partial	2	2	-	-
20	150	Sealed	2	0	26.9	9.2
40	150	Sealed	2	0	25.8	8.2
60	150	Sealed	2	0	27.3	11.5
20	212	Partial	2	0	28.0	50.0
40	212	Partial	2	1	26.7	47.0
60	212	Partial	2	0	27.6	44.8
20	212	Sealed	2	0	23.9	9.3
40	212	Sealed	2	0	24.0	9.1
60	212	Sealed	2	0	25.9	3.1

Table 12. Loss of Weight of Contents of Pint Jars Filled at Varying Temperatures to Constant Headspace of 150 cc. and Processed at 240° F. (Pressure Slowly Released)

Processing Time Minutes	Temp. of Filling Deg.F.	Condition of Seal	No. of Jars	No. of Covers Broken	Vacuum Inches	Vent Loss Grams
20	70	Partial	2	0	27.6	6.2
40	70	Partial	2	0	28.5	10.3
60	70	Partial	2	0	28.2	6.9
20	70	Sealed	2	0	25.1	1.6
40	70	Sealed	2	0	27.0	0.9
60	70	Sealed	2	0	25.8	10.2
20	150	Partial	2	0	27.9	16.4
40	150	Partial	2	0	28.2	15.3
60	150	Partial	2	0	27.3	22.1
20	150	Sealed	2	0	25.2	6.4
40	150	Sealed	2	0	25.7	6.4
60	150	Sealed	2	0	26.8	8.6
20	212	Partial	2	0	28.0	22.4
40	212	Partial	2	0	27.4	36.7
60	212	Partial	2	0	26.7	19.1
20	212	Sealed	2	0	26.2	12.7
40	212	Sealed	2	0	26.2	9.8
60	212	Sealed	2	0	26.5	6.5

Table 13. Average Vent Losses During Processing at 240° F.

Headspace	No. of Jars	Partly Sealed		Fully Sealed	
		Pressure Released Rapidly Grams	Pressure Released Slowly Grams	Pressure Released Rapidly Grams	Pressure Released Slowly Grams
6c.					
54	72	93.2	40.0	13.0	12.0
65	72	75.7	35.1	7.2	6.7
150	72	18.4	17.3	6.3	7.0

steam. This release of pressure takes from 10 - 12 minutes.

Discussion of Tables 7 to 13 and Graph 1.

A. Effect of Slow or Rapid Release of Pressure

In Tables 7, 8 and 9, where the pressure in the pressure cooker was rapidly released as compared to Tables 10, 11 and 12, where the pressure was slowly released (usual method), there was no significant effect on the vacuum obtained in the jars. The data show that out of 54 duplicate tests, 30 gave greater venting loss when the pressure was rapidly released, 11 were approximately the same, and 12 tests showed greater losses when the pressure was slowly released. Table 13 gives these data in tabular form. See also Graph 1.

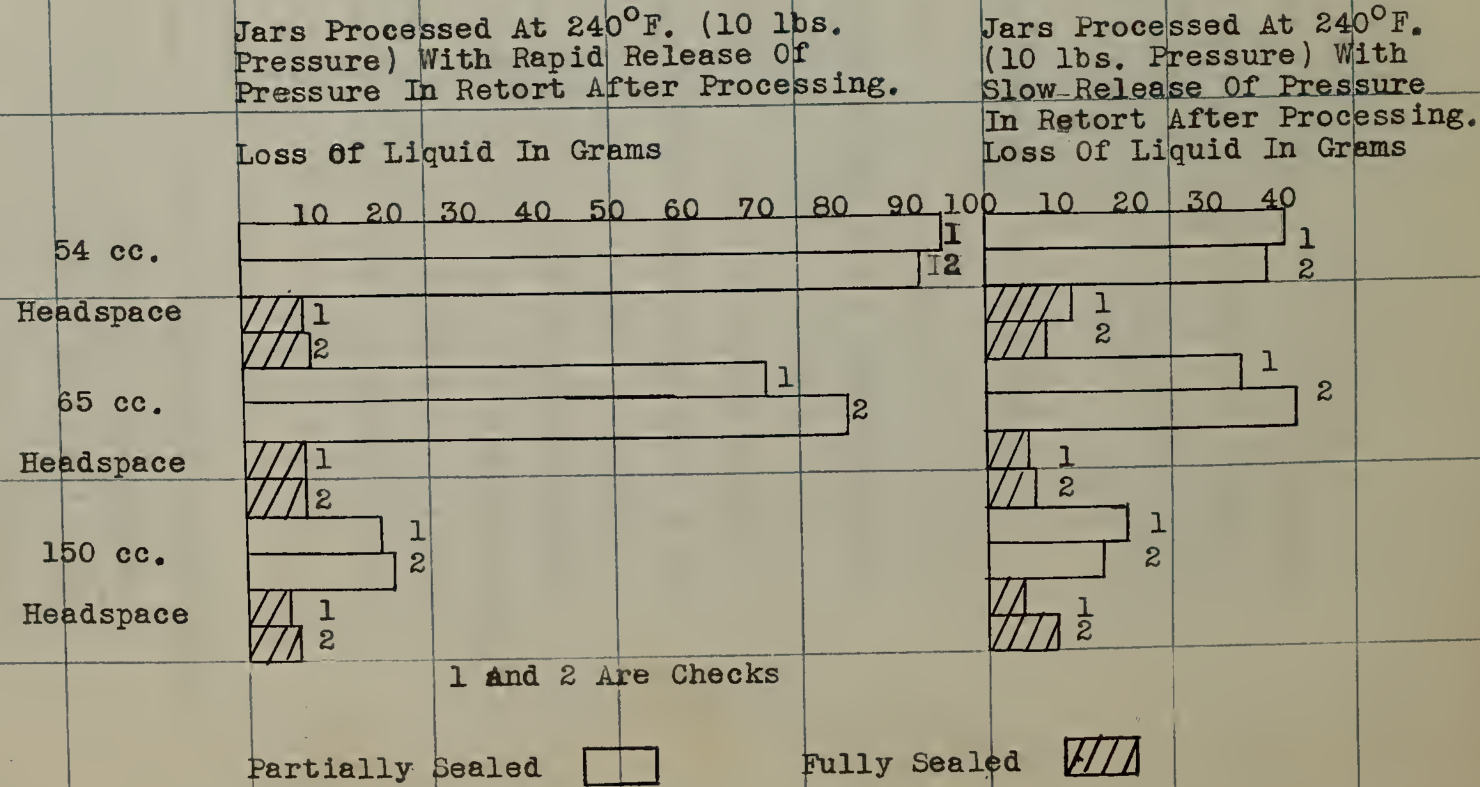
Hence, slow release of pressure from the cooker is the preferred method to avoid excessive vent losses.

Of the 216 pint jars used in these tests the number of broken covers was only 11, all but 2 being in the partially sealed series. The rapid or slow release of pressure had no effect upon breakage inasmuch as the respective numbers of broken covers was 5 and 6.

B. Vent Losses in Fully Sealed versus Partially Sealed Jars

In all but one of the 108 tests made, the fully sealed jars had less venting loss than the partially sealed jars. The average loss of weight of 106 partially sealed jars was 47 grams, whereas for 107 fully sealed jars the weight loss was only 8.0 grams. In

Graph I. Average Vent Losses Of Liquid In Pint Jars Processed Partially And Fully Sealed.



other words, the levels of liquid were much higher in the jars fully sealed previous to processing. This is a very important point in home canning.because loss of jar contents results not only in actual food loss but in an unattractive appearance and a greater liability to spoilage and air entrance.

C. Relation of Venting Loss to Fill of Jar (Headspace)

Recapitulation of some of the data in Tables 7 to 12 in Table 13, show that the greater the original headspace in the jar, the less is the venting loss during processing. For example, when the headspace was 54 cc. the average venting loss when the retort pressure was released rapidly was about 5 times as great in the partially sealed jars as when the headspace was 150 cc. Similar results hold for jars where the pressure was slowly released. In the fully sealed jars, only slight increases in vent loss were obtained at the smaller headspace. In no case did the average vent loss in fully sealed jars exceed 13 grams, whereas in the partially sealed jars, this loss reached a maximum average of 93 grams at a headspace of 54 cc.

This experiment shows that marked vent losses occur in partially sealed jars where the headspace is small. These vent losses become smaller with an increased headspace. Fully sealed jars show only negligible vent losses during processing regardless of headspace.

D. Effect of Length of Process on Vent Losses

There appeared to be no significant differences in vent losses among the 20, 40 and 60 minute processes at 240° F. Probably the reason for this is that the jars upon being placed in the retort gradually heat up, expel the gases, including some water vapor as well as liquid and soon reach a pressure equilibrium with the retort. This takes place in 20 minutes or less and hence only slight differences occur in vent losses at longer processing periods. In other words, after a few minutes in the retort, nearly all the vent losses have occurred which will occur.

It is probable that much of the loss of liquid during processing occurs as mechanical loss by violent agitation or bubbling rather than as gas (water vapor). The fact that in the jars which had a 150 cc. headspace the vent loss was small (See Table 13 and Graph 1) seems to substantiate this fact.

Relation of Filling Temperature to Vent Losses

Filling temperature had no consistent influence upon vent losses. This may be explained by considering that regardless of the filling temperature, no boiling, serious bubbling or mechanical losses will occur until the boiling temperature is reached. Since all jars have to pass through the same temperature range of 212 to 240° F., it is reasonable that all would suffer approximately the same vent losses regardless of filling temperature - providing of course, the headspace was the same.

IV. HEAT PENETRATION STUDIES ON PARTIALLY AND FULLY SEALED GLASS JARS

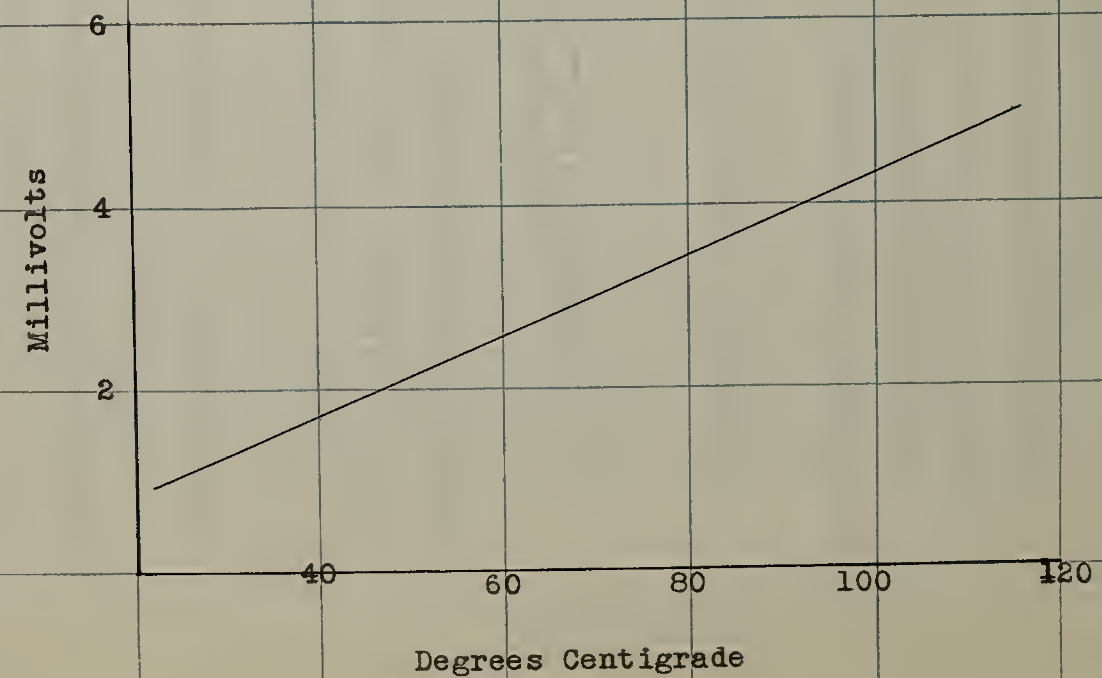
A. Calibration of Thermocouple.

The object of subjecting foods to heat is to destroy spoilage agents and pathogenic microorganisms and to produce a vacuum. The processing time is that consistent with accomplishing the primary object of sterilization and not causing a destruction of the plant or fruit tissue. Theoretically, the rate of heat penetration should not be affected by fully sealing a jar during processing.

A copper-constantan thermocouple was conducted through holes drilled in the glass cover of a pint jar. The wires were sealed to the glass with a paste of litharge and glycerine to prevent the escape of gases. The thermocouple was standardized by means of an oil bath and a Bureau of Standards calibrated thermometer. A Leeds and Northrup Potentiometer Indicator was used to determine the millivolts indicative of temperature. The oil was heated to 120° C. and the millivolt reading was taken at every 5° increase in temperature. The oil was then allowed to cool and the millivolt reading was taken at every 5° decrease in temperature. The average reading of the ascending and descending temperatures was taken for plotting Graph 2.

Graph 2. Standardized Copper - Constantan Thermocouple

Cold Junction At $0^{o}C$.



Processing was carried out in both the water bath and pressure cooker. In the former, heat was applied slowly and the water kept at 212° F. during the experiment.

The same copper-constantan thermocouple was used in the calibration of heat penetration studies of jars processed in a pressure cooker at 240° F. The thermocouple was conducted through an escape valve on the cooker and sealed to prevent loss of pressure.

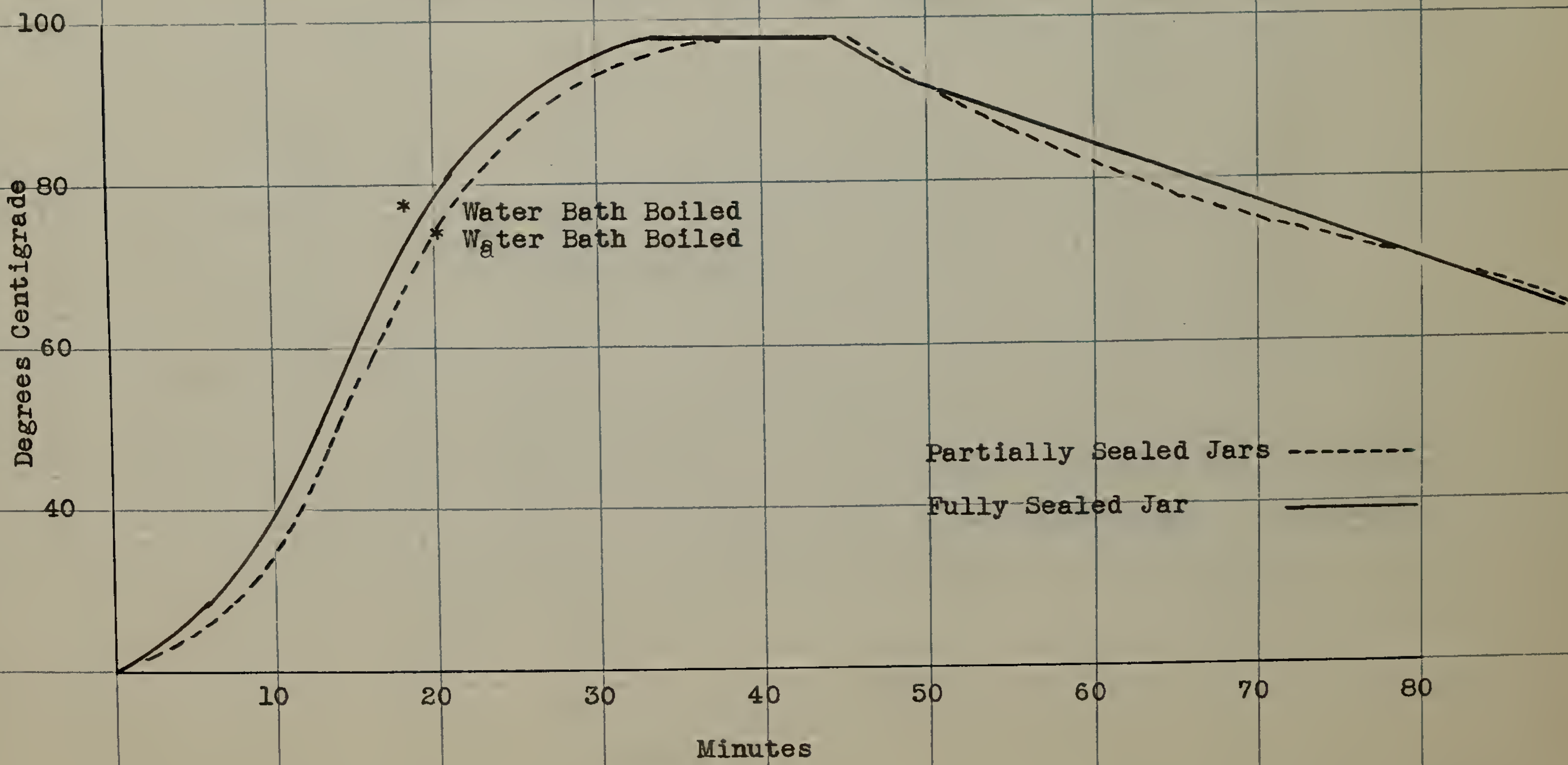
The retort was heated slowly to permit a slow rise of temperature.

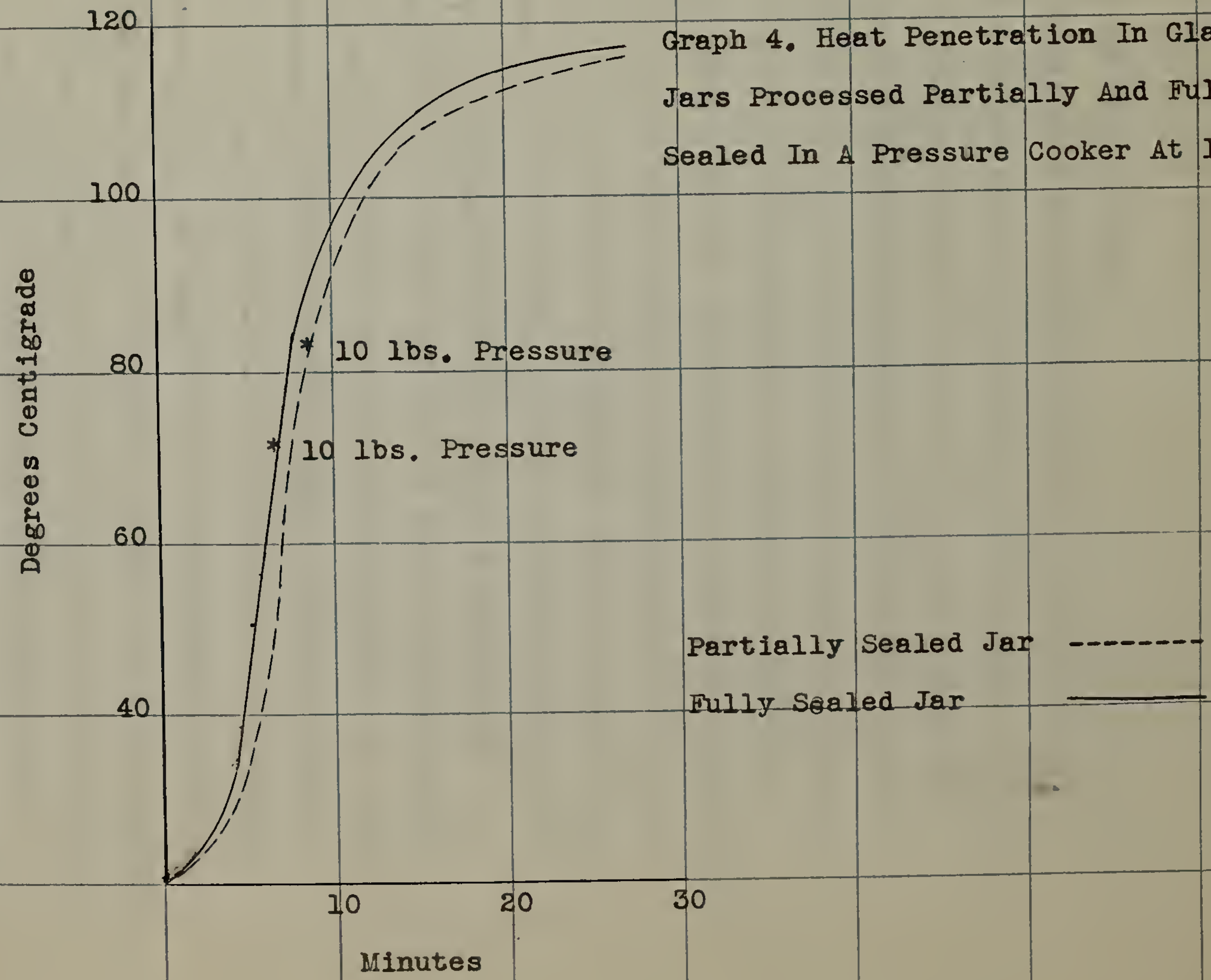
B. Determination of the Rate of Heat Penetration in Fully and Partially Sealed Jars of Water

In order to determine if any differences exist in the transfer of heat to partially sealed or fully sealed jars, a series of experiments were made, the results of which are presented in Graphs 3 and 4.

These data show clearly that there are no marked differences in the penetration of heat in partially sealed and in fully sealed glass jars of water processed either in the water bath at 212° F. or in the pressure cooker at 240° F.

Graph 3. Heating And Cooling Of Glass Jars Processed Partially And Fully Sealed In A Water Bath





Graph 4. Heat Penetration In Glass Jars Processed Partially And Fully Sealed In A Pressure Cooker At 10 lbs.

V. INTERNAL PRESSURE DEVELOPED IN GLASS JARS DURING PROCESSING

A. Water Bath Processing

Normally, jars of canned foods are only partially sealed (wire bails not pulled down) previous to heat treatment. The seal is completed only after the jars have been removed from the cookers. This operation requires considerable time, care in placing the jars in the cooker and removing them, and has in it an element of danger from burns. Tin cans are processed in a fully sealed condition. Would it not be possible to process glass jars in the same way? Preliminary experiments showed that this could be done in canning some products. The whole matter of the internal pressures developed in glass jars during processing is studied in this experiment with a view of determining the feasibility of processing fully sealed jars. The word "fully" is used with the reservation that the jar is fully sealed to outward appearances. Actual experimental evidence shows that venting occurs in these "fully" sealed jars as well as in the partially sealed - the only difference being one of magnitude of pressure.

In order to study this pressure in glass jars of water during processing, a 0.6 centimeter hole was bored in the cover to allow direct attachment of a manometer tube. The manometer was an open U-tube containing mercury and was fitted to the jar opening by means of a rubber tube. In the case of retort processing, the rubber tube was passed through the cover of the retort. The rubber tubing leading to the jar cover was vulcanized to the cover with carbon disulfide to make a firm seal.

New rubber rings and bails were used in each determination. The initial temperature of the water in the pint jars was standardized at 70° F.

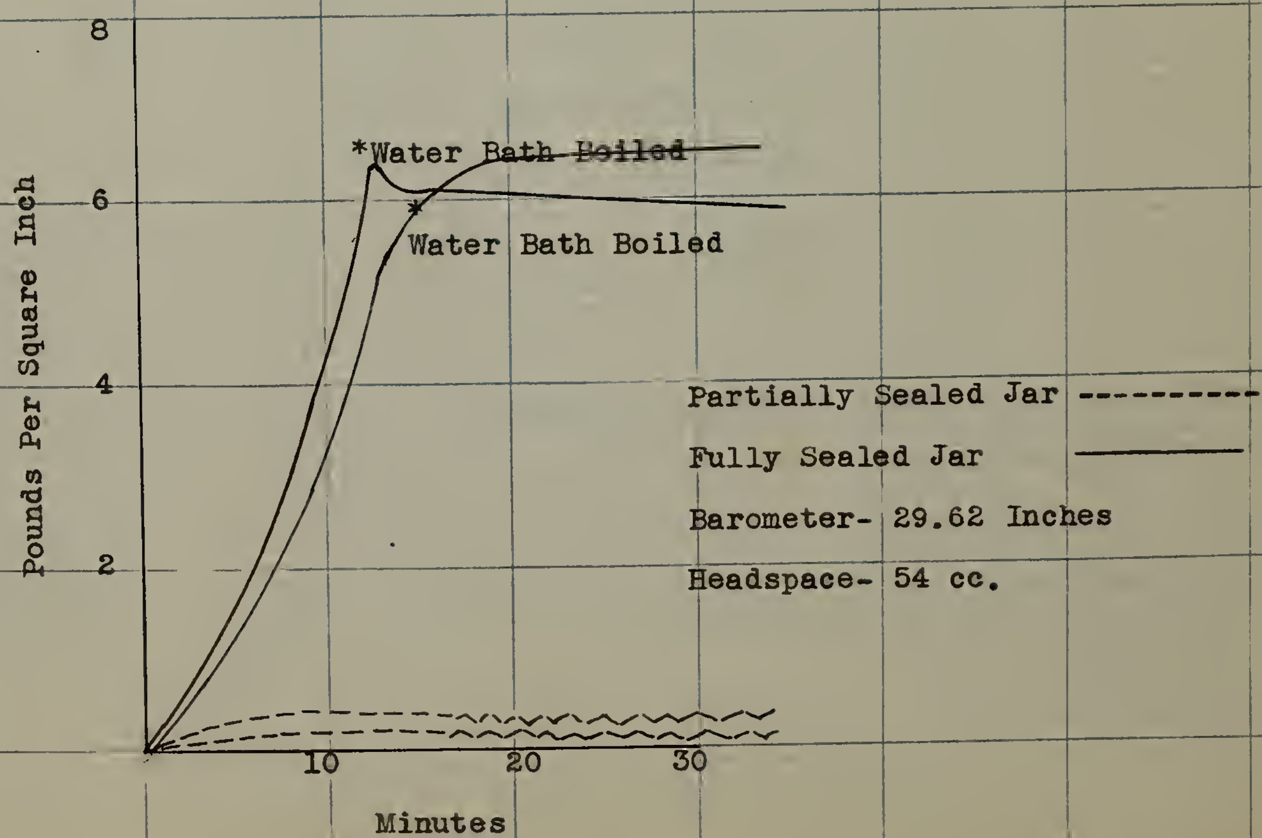
The data for water bath processing at 212° F. are presented in Table 14 and show that the average pressure at which venting occurs in partially sealed pint jars is less than 0.5 pounds per square inch, whereas in the fully sealed, the pressure developed reached approximately 7 pounds. The latter pressure is not excessive nor does it appear to significantly increase the breaking hazard. Graphs 5 and 6 are self-explanatory and show the speed and intensity of pressure development in partially sealed and fully sealed pint glass jars. In the partially sealed jars, venting occurred in an average of 6 minutes, while for the fully sealed jars, venting did not take place until after 24 minutes. That is, a much greater pressure and longer time are necessary to produce venting in the fully sealed jars. It has been previously pointed out that approximately the same vacuum results by the use of two methods of sealing.

Attention is called to Graphs 5 and 6, which show exactly when venting occurred at the different headspaces and after how long a time. In general, venting occurred within one to three minutes from the time the water bath reached the boiling point.

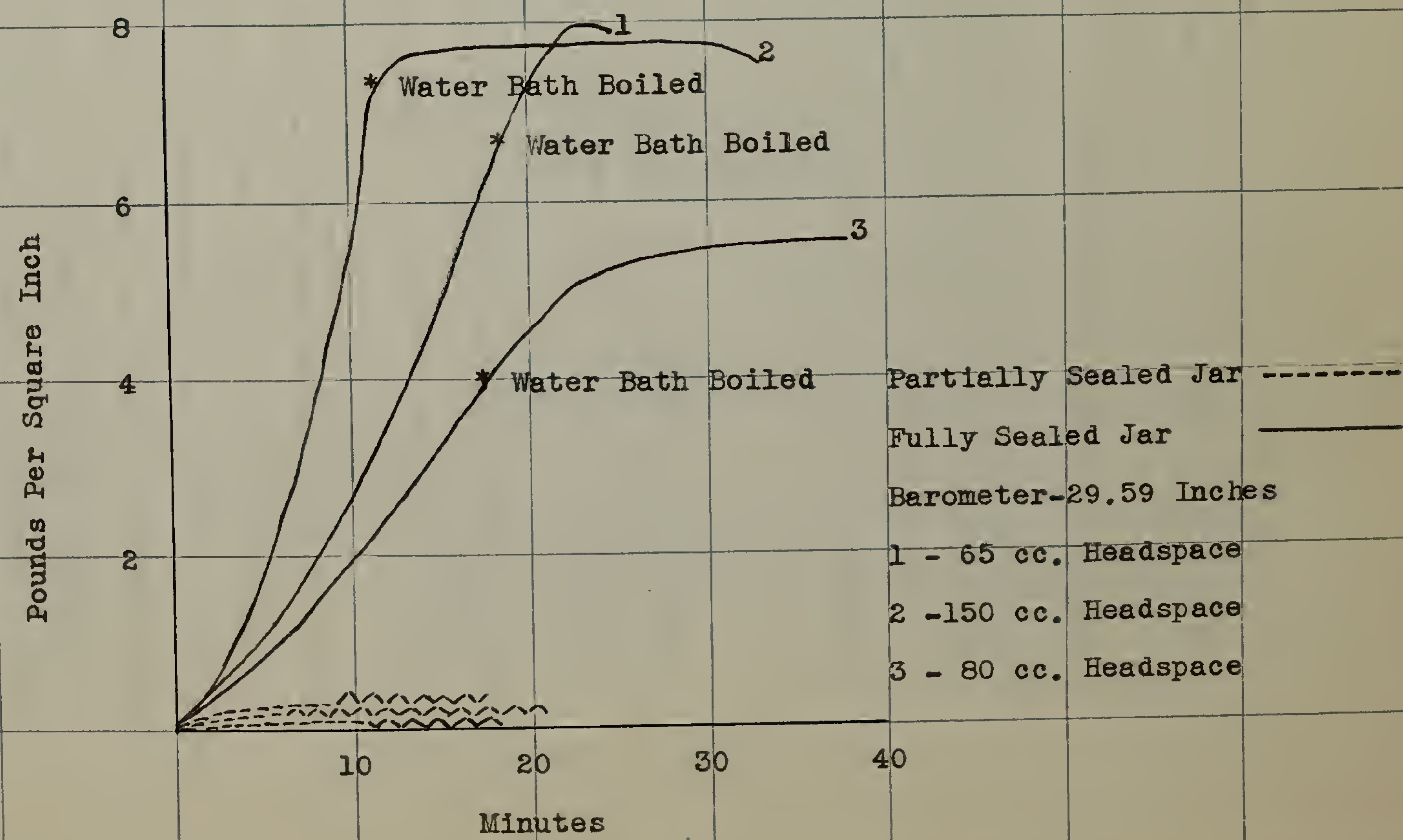
Table 14. Pressures Developed in Pint Jars Filled with Water at 70° F. during Processing. Initial Water Bath Temperature 70° F. and Brought to 212° F.

Series No.	Pressures at Which Venting Occurred		Time Required before Venting Occurred	
	Partially Sealed Jars	Fully Sealed Jars	Partially Sealed Jars	Fully Sealed Jars
	Lbs. Pressure Per Sq. Inch	Lbs. Pressure Per Sq. Inch	Time in Minutes	Time in Minutes
1	.33	6.30	5	13
2	.16	6.70	7	27
3	.23	7.92	8	22
4	.21	5.50	8	37
5	.24	7.76	3	23
Average	.23	6.83	6.2	24.4

Graph 5. Pressure Developed In Pint Jars Processed Partially And Fully Sealed In A Water Bath.



Graph 6. Pressure Developed In Pint Jars Processed Partially And Fully Sealed In A Water Bath.



This indicates that the evolved water vapor supplemented the internal gas pressure due to expansion of contents and residual gases until the total pressure (approximately 5 to 10 pounds) was sufficient to vent the jar. The form of curve for four of the five jars is very similar. It is possible that occasional jars vent differently. This is to be expected because the tension of the bail varies somewhat among jars and there may be small fissures or poor fitting rubbers which may allow slight venting.

B. Pressure Cooker Processing

The foregoing experiments were repeated using the pressure cooker to obtain a temperature of 240° F. (10 pounds of steam pressure).

The following tables represent the pressures developed in pint jars during processing in a pressure retort at 10 pounds pressure, 240° F.

A hole, about 2 mm. in diameter, was bored in a glass cover and pressure tubing inserted. This joint was sealed with a mixture of litharge and glycerin and allowed to harden. The safety valve was removed from the retort and the pressure tubing was led out through the opening thus formed. The tubing was sealed in the opening to prevent escape of pressure from the retort. The pressure tubing was then connected to an open U-tube mercury manometer.

Plate II. Apparatus for determining pressure developed in glass jars during processing in a pressure cooker

Water was filled into pint jars at 70° F. with varying head-spaces. The glass jar with contents was placed in the pressure cooker. The glass cover with pressure tubing attached was placed on the jar and either partially or fully sealed. The lid of the pressure cooker, with tubing through the safety valve hole, was tightened down to the retort. Heat was applied until steam from water in bottom of cooker had filled the jacket and forced out the air, then the petcock was closed and pressure allowed to develop. The pressure in the cooker was not allowed to exceed 10 pounds but did vary slightly.

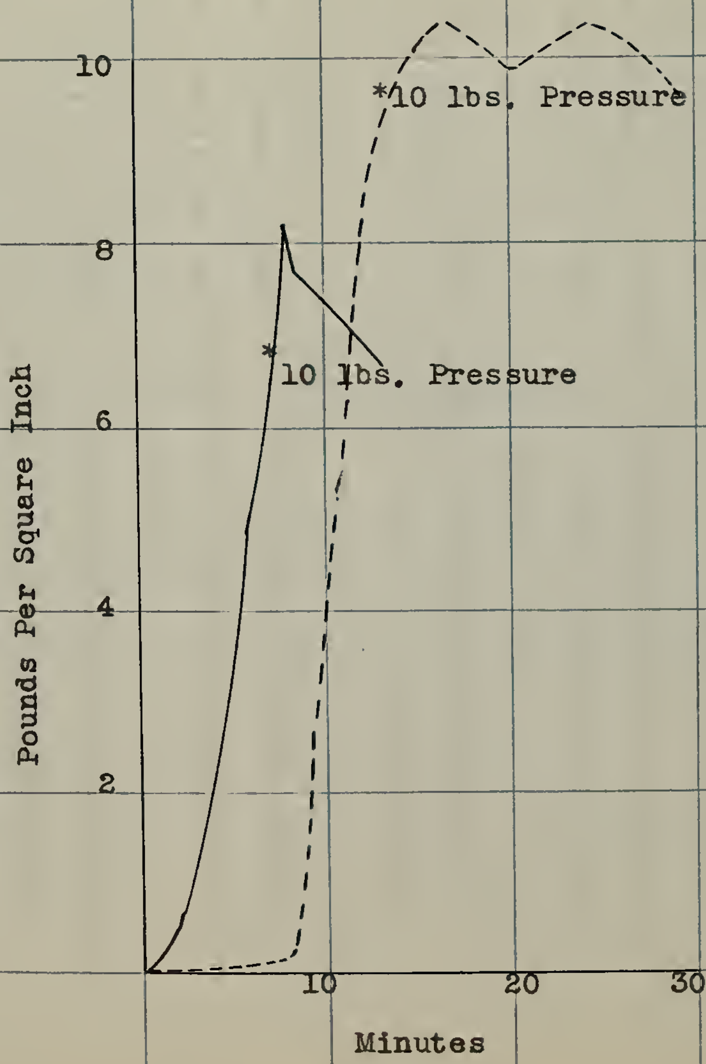
Each jar was subjected to this pressure in the cooker until the mercury in the manometer remained steady or showed a decline from its highest point. Pressure was measured in centimeters of mercury and converted to pounds per square inch.

The time was recorded from the point of placing over the flame, with notations as to when the petcock was closed and when 10 pounds pressure developed. The barometer was read before each calculation was made but final pressures were not corrected for this as variance in results were so great that such corrections would not be significant.

The pressure cooker was cooled and fresh water at 70° F. was placed in it before each determination so that pressure would not develop more rapidly in one case than in another. New bails and new rubber rings were used in each determination.

Table 15. Pressures Developed During Processing Pint Jars at 10 lbs. Pressure, 240°F. Initial Temperature of Water in Jars, 70°F.

Series No.	Pressures at Which Venting Occurred		Time Required before Venting Occurred	
	Partially Sealed Jars	Fully Sealed Jars	Partially Sealed Jars	Fully Sealed Jars
	Lbs.pressure Per Sq.Inch	Lbs. pressure Per Sq. Inch	Time in Minutes	Time in Minutes
1	5.99	5.87	16	14
2	10.65	8.20	20	8
3	10.70	6.00	8	19
4	8,96	3.6	12	No definite time
5	11.50	7.5	14	No definite time



Graph 7. Pressure Developed In Pint Jars Processed Partially And Fully Sealed In A Pressure Cooker At 240°F.

Partially Sealed Jar - - - - - - -

Fully Sealed Jar ———————

In each case, at the time of partially or fully sealing a slight rise in the mercury column was noticed. This is presumably due to the headspace at time of sealing.

The data obtained in this series of experiments do not seem to agree with theoretical considerations. For example, the pressures at which venting occur in the partially sealed jars are uniformly equal to or greater than that in the fully sealed jars. This is exactly opposite to what was found in the case of water bath processing. It seems probable that at temperatures above 212° F. the actively boiling water in the partially sealed jars was mechanically forced through the relatively large opening between the rubber ring and the jar neck or cover. This probably accounts for the much greater loss of contents in the partially sealed jars. As shown in Graph 12 and Table 15 the pressures developed in the partially sealed jars are much higher than those in the fully sealed, viz., 9.56 as compared to 6.23 average. Reasons for this are not entirely clear. It seems probable that the equipment was faulty and that before definite conclusions can be reached further work must be done under more carefully controlled conditions.

Table 15 and Graph 7 are representative of the data obtained with the equipment which was used. Because of the inability to conciliate the high pressures developed in partially sealed jars processed in a pressure cooker with the theory, the accuracy of this graph and the data in Table 15 may be questioned and no claim is made for their accuracy.

The curve for partially sealed jars after it reaches the boiling point shows a series of oscillations and resembles the well known sine curve. These oscillations are due to the building up and blowing off of pressure within the jar and in general, vary in a range of approximately two pounds per square inch.

Venting occurs in the pressure cooker processed jars within about two to three minutes after cooker reached the desired 10 pounds pressure. However, only three jars out of ten jars vented at pressures of 10 pounds or over, the others vented at pressures varying from two to eight and one-half pounds per square inch of pressure. In view of the fact that venting should not theoretically occur until the internal pressure of the jar exceeds the pressure surrounding it, that is, 10 pounds, this is further evidence that the equipment used was faulty.

VI. PROCESSING FOODS IN FULLY SEALED JARS

Previous determinations of vacuum, heat penetration, vent losses and internal pressures developed during processing have been calculated on water alone. Processing glass jars, fully sealed, offers only minor differences in all calculations except on internal pressures, when compared with the usual method of processing, while partially sealed. The differences in pressures developed in these two methods of processing is immaterial providing the tendency of broken covers is not greater in one method than in the other.

Fruits, vegetables and meat were prepared for canning in the usual way and processed in jars, fully sealed, according to directions in the "Atlas Book of Recipes and Helpful Information." No partially sealed jars were processed as controls, the factor of breakage of glass covers not being standardized well enough to offer comparisons.

New bails and rubber rings were used on each jar. The jars were removed from the pressure cooker or water bath immediately after processing was completed. Results on 200 fully sealed jars processed as described above are given in Table 16.

The jars described in Table 17 were processed in the identical manner of the previous mentioned foods (See Table 16) with the exception that at the completion of the processing period the jars remained four or five minutes in the cooker and bath, water drained, until it was certain that a vacuum had begun to develop in the glass jar.

The percentage of covers broken when food is processed in jars fully sealed is not too high to attribute to normal weakness in the glass. More covers were broken when the glass jars were processed in the water bath then in the pressure cooker.

There is a relatively large pressure in fully sealed jars when compared with partially sealed during processing in a water bath. With foods there is slower cooling. The wire bails cool

Table 16. Breakage of Glass Covers of Fully Sealed Jars Processed at 240°F. and 212°F. and Removed Immediately from the Source of Heat

Product	Pressure Cooker			Water Bath		
	No.of Jars Processed	No.of Covers Broken	Breakage	No.of Jars Processed	No.of Covers Broken	Breakage
	Pints		Per cent	Pints		Per cent
Corn	5	0	0	6	2	33
Tomatoes	10	0	0	9	1	11
Spinach	20	4	20	25	1	4
Lima Beans	3	0	0	3	2	66
Meat	9	0	0	10	2 *	20
Peaches				20	0	0
Squash	3	0	0	3	1	33
Carrots	9	0	0	9	1	11
Raspberries				8	0	0
Blueberries				48 - ½ pints	0	0

* Three rubbers pushed out from under their covers when processed in the pressure cooker. Two rubbers pushed out when processed in the water bath.

Table 17. Breakage of Glass Covers of Fully Sealed Jars Processed at 240°F. and 212°F. but not Removed from Processor until Vacuum had Developed

	Pressure Cooker			Water Bath		
Product	No.of Jars Processed	No.of Covers Broken	Breakage Per cent	No.of Jars Processed	No.of Covers Broken	Breakag Per cen
Corn	32 pts.	0	0	6 pts.	0	0
Tomatoes	14 "	0	0	14 "	0	0
Tomatoes	8 qts.	0	0	7 qts.	0	0
Lima Beans	10 pts.	1	11	10 pts.	0	0

rapidly in the atmosphere and the combination of pressure exerted and strain due to contraction of the wires in contact with the glass together with the marked differences in temperature between cover and bail, cause excessive breakage. In every instance where covers broke, the break was traced to the point of contact of wire bail and the shoulder of the cover.

A smaller percentage of covers on fully sealed jars was broken when processed in a pressure cooker. The reason for this is not clear.

The rubber rings on the jars processed had no tendency to push out on any product except meat. The fat from the meat prevented adhesion of the rubber to the glass.

The foods processed in the fully sealed jars were stored with jars of food that had been processed partially sealed. There was no variation in keeping quality showing that the thermal treatment had been adequate. This is consistent with the studies conducted on heat penetration showing no differences in heat transfer in the partially or fully sealed jars.

The improved attractiveness of the jars of food processed in the fully sealed jars, due to small vent losses was very marked and was consistently observed. The upper layers of food in the partially sealed jars were often above the level of the liquid and greatly detracted from their appearance. Oxidation at the surface of the food was also more marked in the partially sealed jars, probably due to somewhat greater gas retention.

These food processing results cannot be construed too literally nor even translated in terms of commercial practice. Larger numbers of jars and more refined and better controlled conditions must be used before definite or reliable deductions can be made. It is proposed to continue these experiments.

VII. SUMMARY

1. Two methods of determining vacuums in glass jars of food were compared. The M.S. C. method, which utilizes a vacuum desiccator and suction pump, was perfected and gave accurate and consistent readings of partial vacuums in freshly sealed glass jars. The Gray method of vacuum determination is also reliable and checked the M.S.C. method.

2. The vacuums present in sealed glass jars of food were high, averaging well over 20 inches of mercury.

3. In water bath processing at 212° F., maximum vacuums were attained in either partially or fully sealed glass containers of water after about 15 minutes. Approximately the same vacuum was attained regardless of whether the jars were partly or fully sealed before the heat treatment.

4. Temperature of filling or headspace of the jars had no effect upon the final vacuum in the jars after processing.

5. In fully sealed jars of water processed in either the pressure cooker or water bath there was less breakage of covers than in the partially sealed jars subjected to the same treatments.

6. Slow release of pressure in the pressure ccoker largely avoided excessive vent losses as compared to rapid release of pressure.

7. Vent losses were very much greater in partially sealed than in fully sealed jars of water processed in the pressure cooker.

8. The greater the original headspace in the jar, the less the venting loss became.

9. Filling temperature had no significant effect upon vent losses.

10. There was practically no difference in the penetration of heat into jarsof water either partially or fully sealed.

11. In the water bath in partially sealed jars, venting occurred at approximately 0.5 pound pressure in 6 minutes. In the fully sealed jars, 7 pounds of pressure were attained when venting occurred after about 24 minutes, under comparable conditions. Venting usually occurred in from 1 to 3 minutes after the water bath reached the boiling point.

12. The data on internal pressures in glass jars processed in the pressure cooker are inconclusive and will be repeated. The internal pressures measured were somewhat higher in the partially sealed jars. This does not agree with theoretical considerations.

13. Breakage of jar covers usually occurred after the jars had been removed from the source of heat. There was much less breakage when the jars were not removed from the processor immediately.

14. Of the 200 jars of assorted foods processed by the fully sealed method and removed immediately from the scurce of heat, the glass cover breakage was 7 per cent. Of the 101 jars which were allowed to cool for 5 to 6 minutes before removing from the processor, the breakage was only 1 per cent.

15. There was no difference in palatability or keeping quality of foods canned either in partially or in fully sealed jars. Because of higher liquid levels, the latter were the more attractive.

16. There does not seem to be any increased element of physical danger in processing glass jars of food that are fully sealed. The method is given tentative approval.

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IX. ACKNOWLEDGMENT

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