1936

A study of some factors involved in the thermal treatment of all-glass containers

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A STUDY OF SOME FACTORS INVOLVED IN THE THERMAL TREATMENT OF ALL-GLASS CONTAINERS

LEVINE - 1936

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Thesis submitted for
the degree of
Master of Science

MASSACHUSETTS STATE COLLEGE, AMHERST

May 2, 1936

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INTRODUCTION AND REVIEW OF LITERATURE

"Despite the fact that over a hundred years ago Appert used glass as the container for his products, the glass package is a rather new entrant in the field of modern commercial packing. For this reason information of a strictly scientific nature regarding glass packed foods is limited." This statement was made by Ford (2) and offers a reasonable suggestion as to why the field for investigation of the glass package is undeveloped. Because of the ease of handling in rapid mass production and the negative breakage factor, tin became the popular medium among the commercial interests. However, the all glass container has several advantages over its metal counterpart which are responsible for its extensive popularity among home canners and small scale, quality producers. The glass container has a reuse value, attractive appearance and does not require expensive sealing equipment.

What little original research investigation on this subject of the glass container undertaken so far has received its stimulus from glass manufacturers and unorganized home canners.

A review of the literature on glass container research shows that heat penetration studies and experiments on processing have monopolized the field of investigation. A scientific study of the closure of the all-glass container has been practically neglected. Maclinn (3) in 1933 started an investigation of this phase of canning and introduced the Massachusetts Method of processing (sterilizing) the all-glass fruit jar. By this method the wire bail or clamp is placed in the tightened position before processing. This is commonly referred to as being "fully sealed."

Because Maclinn was practically a pioneer in this research, the main object of this paper is to corroborate the newer phases of his investigation and establish beyond all doubt the safety and efficiency of the "fully sealed" or Massachusetts Method in the preservation of foods.

DESCRIPTION OF ALL-GLASS JARS AND HOW THEY ARE PROCESSED

The all-glass container consists of a glass jar and cover, a flexible rubber ring, and a wire bail which clamps the cover into the sealing position. When the wire bail is in place but not clamped tightly, the jar is said to be "partially sealed." In this investigation the term "fully sealed" means that the bail is pressed down in its tightened position.

The common method of processing foods in all glass containers is to submit the jar in a partially sealed condition to a boiling water bath or a steam pressure retort for a specified period of time. This heating destroys microorganisms and insures keeping quality and safety of the product. White (5) states that if spoilage does occur the chances are that there has been an inward flow of air through a defective closure. In addition to destroying and inactivating microorganisms, the heat expands the gases including water vapor, which create a pressure, lift the lid of the jar, and permit the gases to escape through the partially sealed closure. As soon as the heating period is completed, the wire bail is clamped into the tight or fully sealed position and the jar and contents cool with the subsequent formation of a vacuum. As Clark et al (1) have stated, one of the most important functions of a vacuum in canned foods is the inhibiting action on the growth of aerobic bacteria and some molds.

DEFINITION OF VACUUM AND PRESSURE

Vacuum is generally expressed in "inches of mercury" while pressure is expressed in "pounds per square inch." Vacuum is simply the absence of pressure. If a closed can is heated, the contents of the can tend to expand and exert a pressure outward greater than the atmospheric pressure on the can and it is said that a pressure exists within the can. Suppose the pressure in the can is sufficient to support a column of mercury 50 inches high and the atmospheric pressure is sufficient to support a column 30 inches high, then the difference between the height of the two columns, 20 inches, represents the pressure. A column of mercury 20 inches high having a cross section of one square inch weighs approximately ten pounds. Thus, there is a pressure in the can of ten pounds per square inch (1). For example, if the pressure in the can is sufficient to support a column of mercury only 10 inches high it is said that the can has a partial pressure of 10 inches less than atmospheric pressure or, normally, a vacuum of 20 inches.

PROBLEM

There is often a marked loss of liquid contents from jars processed in the customary partially sealed condition. This loss is much greater in the case of steam pressure processing. Previous investigation has suggested that high tension on the wire bails, i.e. clamped position of the bails during processing tends to alleviate this undesirable condition. See Plates I, II, and III. In addition, fully sealing the jar prior to the processing period would not require the handling of the hot wire bails and jars immediately after removal from the processing tank.

Plate I. Position of bail in partially (1) and fully (2) sealed jars of corn

Comparison of Liquid Level in Jars Processed Partially and Fully Sealed

Plate II. Beets

Plate III. Tomatoes

Note: Fully (1) and partially (2) sealed jars of each lot were filled to the same level and processed together at 240° F.

Although commonly called "fully sealed" when the bail is in the high tension position, this term is technically a misnomer because when sufficient pressure is developed within the container, the glass cover will lift slightly, permitting a release of the expanding gases and vapors as in the partially sealed condition. Regardless of whether the jar is partially or fully sealed before processing, this so-called "venting" during the average processing period produces approximately the same degree of vacuum.

EXPERIMENTAL PROCEDURE

Methods

Apparatus For The Study of Internal Pressures

In order to study the internal pressures developed during processing in a boiling water bath and in a steam pressure retort, it was necessary to connect the inside of a jar with an open U-tube manometer. To do this, a 10 mm. hole was drilled into the side of a pint jar. Through this hole was inserted a metal U-tube so that one end opened into the headspace area. The other end of the tube was connected by 8 mm. pressure tubing to an open U-tube manometer containing mercury. The union of glass and metal tubing was sealed by means of rubber gaskets tightened

Plate IV. Apparatus for the determination of internal pressures.

down with threaded nuts.

In this investigation of pressures another type of experimental jar also proved to be successful. An exact duplication of a glass cover was made out of aluminum. Aluminum was chosen as the metal because of its rust resistance and light weight. A one-eighth inch brass tube, 2.5 inches long, was threaded into a hole in this aluminum cap and was connected to the V-tube manometer by means of 8 mm. pressure tubing.

For steam pressure retort determinations the safety valve in the cover of the retort was removed and the pressure tubing attached to a brass tube inserted in the hole. All connections were sealed with a mixture of litharge, glycerine, and cement. The volume of the tubing system was 123 c.c. and, being a constant, was not added to the varying headspaces used. Headspaces include the headspace under the cover when the cover is on the jar. Plate IV shows a photograph of this pressure determining apparatus.

Method of Determining Amount of Headspace Under Jar Cover

It is necessary to determine the volume of headspace in the cover when the cover is on the jar because the overlapping lips of the jar and the cover make a difference of as much as 20 c.c. in the headspace. To make this determination a dry pint jar complete with cover, bail, and rubber ring was weighed. The sealed jar was then immersed into water, the seal was broken, and the jar was filled with water so that no air space was left in the jar. The jar was then fully sealed under water and removed. After drying the outside of the jar, the jar and contents were weighed. This weight minus the weight of the empty jar is the total volume in cubic centimeters of the jar when the cover is on it. In order to find the volume of the jar alone without the cover, the dried empty jar was weighed, filled with water, and reweighed. The weight of the water required to fill the jar is the volume of the jar in cubic centimeters. This latter volume when subtracted from the total volume of the jar and cover gives the "cover volume" or headspace contained in the cover when the cover is on the jar.

All water used for these determinations was standardized at 70° F. and had a specific gravity of 1.00. A gram of water having a specific gravity of 1.00 has a volume of one cubic centimeter. Ten determinations were made for glass jars manufactured from several different molds. Table 1 gives the maximum, minimum, and average volumes for each mold set. Maximum and minimum figures are based on the cover volumes. The average cover volumes for all the jars tested was 15 c.c.

Table 1. Volumes of Pint Jars and Covers Manufactured from Different Molds

Mold		Total Volume	Jar Volume	Cover Volume
		c.c.	c.c.	c.c.
	Maximum	551	530	21
1	Minimum	542	528	14
	Average	546.5	530.9	15.6
	Maximum	549	528	21
2	Minimum	540	530	10
	Average	543.9	529.6	14.3
	Maximum	550	528	22
4	Minimum	548	536	12
	Average	546.8	530.6	16.2
	Maximum	544	523	21
6	Minimum	540	527	13
	Average	542.5	525.4	17.1
	Maximum	547	527	20
7	Minimum	542	533	9
	Average	545.9	530.2	15.7
	Maximum	544	525	19
8	Minimum	542	531	11
	Average	544	529	15

Method of Securing a Uniform Headspace

In order to secure a standard method for obtaining uniform headspaces in the large number of jars used throughout the investigation, a simple instrument modeled after the commercial canners' displacing machines was used. See Plate V. A wooden block 5 inches long was turned so that it would just fit through the mouth of an all glass jar. The block was boiled in oil for 30 minutes and then soaked for 24 hours to prevent later absorbtion of water. Twelve rings were then scored in the block at regular intervals spaced 1/8" apart and three holes were bored in each ring so that when pegs were inserted into the holes of any one ring the instrument would enter a jar only as far as these pegs allowed. Each set of holes was tested for its displacement as follows:

The jar was weighed full of water, the instrument was used and the jar reweighed. This was checked by refilling the jar with the calculated amount of water displaced. In each case the refilling brought the level of the liquid to the top of the jar. The water used was tested for a specific gravity of 1.00 and also was weighed to check.

Table 3 shows the liquid displacement in cubic centimeters for each ring on the instrument. Ring No. 1 is the lowest ring.

Table 2. Calibration of Block for Producing Uniform Headspace in Jars

Ring No.	Displacement
	c.c.
1	2
2	10
3	17
4	22
5	27
6	33
7	40
8	46
9	54
10	60
11	65
12	74

Plate V. Headspace adjustment instrument

Methods of Determining Vacuums

The methods used to determine the vacuums of the all glass jars were the Vacuum Desiccator (Plate VI) and Water Displacement Methods as described by Maclinn and Fellers (4).

Vacuums

Effect of Type of Seal on Vacuum Formation

Table 3 shows the results of vacuum determinations made on fully sealed and on partially sealed jars filled with water at 70° F. and processed in a boiling water bath for 5, 10, 15, and 20 minutes. There is little difference in the vacuums formed in jars processed by the fully sealed and by the partially sealed methods for the same period of time. Because of inherent differences in canning methods of glass and tin containers, the former usually have a higher vacuum after thermal treatment. This is because the tin can is completely sealed and the glass jar incompletely sealed during thermal treatment.

A vacuum of 20 inches or more is so well above the safety line that a difference of one or two inches due to the condition of the seal at the time of processing is not going to affect the keeping quality of the contents of the jar. The average vacuum considered safe for preserved foods in tin cans is 12 inches according to Clark et al (1).

The data of Table 3 were secured also to check the efficiency of the two methods of determining vacuum in all glass jars as used by Maclinn and Fellers (4) namely: the Vacuum Desiccator Method and the Water Displacement Method. Both methods were found to be in satisfactory agreement in their results. Because good checks can be obtained by using either method, only the vacuum desiccator method was used during the remainder of the investigation.

Table 3. Effect of Type of Seal on Vacuum as Determined by the Vacuum Desiccator and the Water Displacement Methods

Processing time	Vacuum Desiccator Method				Water Displacement Method			
	Vacuum in fully sealed jars		Vacuum in partially sealed jars		Vacuum in fully sealed jars		Vacuum in partially sealed jars	
Minutes	Inches of Hg.		Inches of Hg.		Inches of Hg.		Inches of Hg.	
	Jar 1	Jar 2	Jar 1	Jar 2	Jar 1	Jar 2	Jar 1	Jar 2
5	14.	14.7	17	4	13.9	14.7	17.2	-
10	17.7	17.2	-	24.8	17.1	18.9	18.	18.2
15	20	18.2	25.5	27.5	17.1	18.3	23.2	19.
20	21	-	25	26.75	24.1	4.2	26.5	26.
5	13	12.4	17.5	-	16.5	17.1	18	17.2
10	17.1	17.9	23.5	24.5	18.9	17.4	19.25	25
15	17.9	17.8	25.25	25	15.9	17.1	25.6	24.5
20	18.8	19.4	26.	27.1	14.4	20.4	27	27
5	15	15	16.8	17.25	18.9	-	16.5	18
10	16.9	18.1	25	25	17.4	16.8	19.75	22
15	19.7	20.1	26.5	24.8	18.6	20.4	24.9	26.5
20	19.6	19.	26.5	26.5	17.1	18.	27.25	26.5

Plate VI. Apparatus for the determination of vacuums by the vacuum desiccator method.

Effect of Seal on Vacuums Formed in Pressure Processed Jars

In order to discover the effect of the type of seal during pressure processing on subsequent vacuum formation, a series of pint jars was processed 5, 10, 15, and 20 minutes in a pressure cooker at 10 pounds steam pressure. Duplicate jars were partially and fully sealed: On one set of jars the pressure was released slowly from the retort; on the other set the pressure was released rapidly. The results are shown in Table 4. It is evident from the data in this table that the vacuums formed in jars processed in pressure cookers are practically the same regardless of type of seal when processed and regardless of pressure release conditions.

The only significant difference observed in these jars was in the marked loss of water occurring in the partially sealed jars, especially when the steam pressure was released rapidly.

Time of Venting of Fully and Partially Sealed Jars

Table 5 gives a comparison of the partially sealed and the fully sealed methods as to time of venting. By "venting" is meant the escape of expanded gases and water vapors through the closure due to an excessive internal pressure which forces up the cover slightly to break the seal.

Eight hundred jars were filled with water at 70° and 170° F. and immersed into a 180° F. water bath. Venting was readily discernible by means of the bubbles rising from the jars. As the average processing in a boiling water bath is longer than ten minutes, jars processed with the bails tightened have equally as good a chance of venting as have jars processed in the partially sealed manner. This is further substantiated by the experimental evidence obtained in making a comparison of the vacuums formed in jars so processed.

Table 4. Vacuum Formed in Jars Processed Partially and Fully Sealed at 10 Pounds Steam Pressure

Headspace 32 c.c. Filling Temperature 70° F.

	Pressure released rapidly		Pressure released slowly	
Processing time in minutes	Vacuum in fully sealed jars Inches of Hg.	Vacuum in partially sealed jars Inches of Hg.	Vacuum in fully sealed jars Inches of Hg.	Vacuum in partially sealed jars Inches of Hg.
5	22	27	23.75	28
	22.75	27.2	21.75	28.25
	22.5	27	24.	29
	24.2	25	24.	29.
10	27.1	28	21.75	29
	25	29	25.25	26
	26.5	29	20.25	28
	25	28	24.75	28
15	26	27	24.75	27.8
	24	27	23	29
	25	27.8	25	28
	25.75	28	-	27.8
20	26.9	28	28.75	29.
	25	26.75	24.75	29.
	26	28.25	24.	29.
	27.1	28.	25.	29.

Table 5. Time of Venting of Fully and Partially Sealed Jars Filled with Water and Processed in a Water Bath at 180° F.

Time in Minutes	Number of jars venting			
	Filling temperature 70° F.		Filling temperature 170° F.	
	Fully sealed	Partially sealed	Fully sealed	Partially sealed
1	92	200	69	200
2	64		67	
3	10		16	
4	18		22	
5	10		12	
6	2		4	
7	4		6	
8			4	
Total	200	200	200	200

Vent Losses During Processing

The noticeable loss of liquid in pressure processed, partially sealed jars led to an investigation of the vent losses occurring in jars partially and fully sealed with varying headspaces and processing periods.

The calculations of vent losses were made by weighing the jar, cover, rubber ring, wire bail, and water to the required headspace. After the processing period was over, the jar, still in the sealed position, was allowed to cool to 70° F. and then reweighed. The difference in weight was due to vent losses during the processing period. These data are presented in Tables 6 to 11. The experimental error in weighing jars at 180° F. was found to be 0.16 grams.

Immediately after wieghing, vacuums were determined on the jars by the vacuum desiccator method.

Table 6. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 56 c.c. and Processed at 240° F.

Pressure Released Rapidly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	26.5	75.8
20	70	Full	2	26.0	12.9
40	70	Partial	2	26.5	97.5
40	70	Full	2	26.4	14.8
60	70	Partial	2	27.9	110.2
60	70	Full	2	26.75	4.6
20	180	Partial	2	27.1	106.5
20	180	Full	2	27.0	13.0
40	180	Partial	2	26.5	99.0
40	180	Full	2	27.4	8.9
60	180	Partial	2	28.5	120.4
60	180	Full	2	27.1	4.8

Average loss:

Partially sealed jars - 101.5 grams

Fully sealed jars - 9.3 grams

Table 7. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 56 c.c. and Processed at 240° F.

Pressure Released Slowly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	28.2	25.6
20	70	Full	2	24.9	6.7
40	70	Partial	2	27.6	22.6
40	70	Full	2	26.0	4.3
60	70	Partial	2	27.8	51.9
60	70	Full	2	25.4	4.8
20	180	Partial	2	26.7	29.3
20	180	Full	2	23.5	12.2
40	180	Partial	2	28.1	45.6
40	180	Full	2	27.0	3.3
60	180	Partial	2	28.25	17.2
60	180	Full	2	26.8	7.1

Average loss:

Partially sealed jars - 32 grams

Fully sealed jars - 6.4 grams

Table 8. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 69 c.c. and Processed at 240° F.

Pressure Released Rapidly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	27.8	72.1
20	70	Full	2	27	6.0
40	70	Partial	2	26.8	108.6
40	70	Full	2	26.1	16.4
60	70	Partial	2	28.3	37.5
60	70	Full	2	25.8	8.9
20	180	Partial	2	28.2	93.5
20	180	Full	2	26.75	2.0
40	180	Partial	2	27.4	72.6
40	180	Full	2	27.0	10.0
60	180	Partial	2	27.8	48.4
60	180	Full	2	26.9	5.2

Average loss:

Partially sealed jars - 72.1 grams

Fully sealed jars - 8.1 grams

Table 9. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 69 c.c. and Processed at 240° F.

Pressure Released Slowly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	27.8	21.4
20	70	Full	2	26.8	3.6
40	70	Partial	2	27.4	34.8
40	70	Full	2	27.0	1.5
60	70	Partial	2	28.0	33.9
60	70	Full	2	26.5	7.8
20	180	Partial	2	27.5	40.0
20	180	Full	2	27.0	9.4
40	180	Partial	2	28.2	18.9
40	180	Full	2	27.5	6.2
60	180	Partial	2	27.5	13.0
60	180	Full	2	27.1	2.5

Average loss:

Partially sealed jars - 27.0 grams

Fully sealed jars - 5.1 grams

Table 10. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 97 c.c. and Processed at 240° F.

Pressure Released Rapidly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	28.0	19.4
20	70	Full	2	26.5	2.5
40	70	Partial	2	27.5	24.3
40	70	Full	2	27.0	1.8
60	70	Partial	2	26.9	15.2
60	70	Full	2	26.9	5.5
20	180	Partial	2	27.9	30.7
20	180	Full	2	27.0	6.4
40	180	Partial	2	28.3	22.3
40	180	Full	2	27.0	14.9
60	180	Partial	2	27.5	25.0
60	180	Full	2	26.9	17.2

Average loss:

Partially sealed jars - 22.8 grams

Fully sealed jars - 8.0 grams

Table 11. Loss of Weight of Contents of Pint Jars Filled to a Constant Headspace of 97 c.c. and Processed at 240° F.

Pressure released slowly

Processing time	Temperature of filling	Type of seal	No. of jars	Vacuum	Venting loss
Minutes	Degrees F.			Inches of Hg.	Grams
20	70	Partial	2	27.0	13.7
20	70	Full	2	26.5	3.0
40	70	Partial	2	28.3	15.0
40	70	Full	2	26.9	2.1
60	70	Partial	2	28.0	13.0
60	70	Full	2	26.4	3.3
20	180	Partial	2	27.2	17.5
20	180	Full	2	25.0	2.0
40	180	Partial	2	27.8	13.5
40	180	Full	2	27.0	3.5
60	180	Partial	2	28.0	12.0
60	180	Full	2	27.5	4.4

Average loss:

Partially sealed jars - 12.3 grams

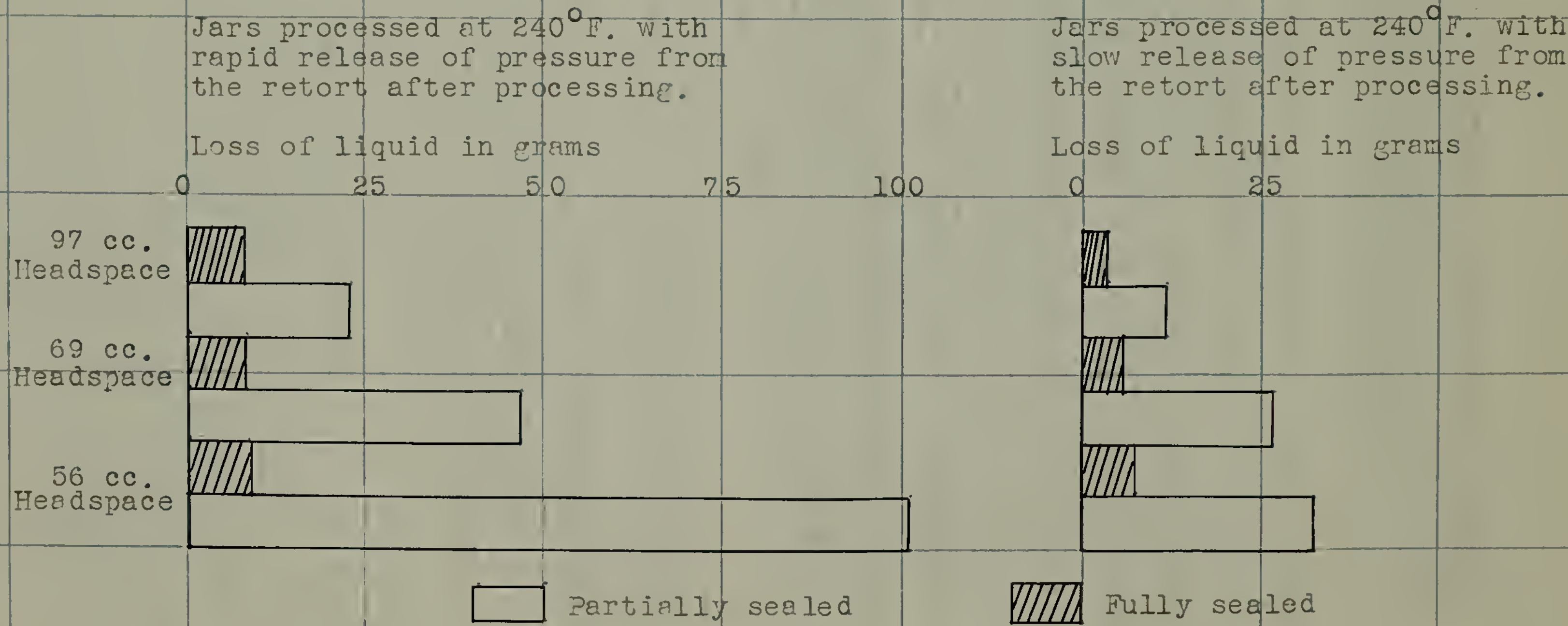
Fully sealed jars - 3.0 grams

Table 12. Average Losses from Venting During Processing at 240° F.

Summary of Tables 6 to 11

Headspace	No. of jars	Partially Sealed		Fully Sealed	
		Pressure released rapidly	Pressure released slowly	Pressure released rapidly	Pressure released slowly
c.c.		grams	grams	grams	grams
56	48	101.5	32.0	9.3	6.4
69	48	72.1	27.0	8.1	5.1
97	48	22.8	12.3	8.0	3.0

Figure 1. Average vent losses of liquid in pint jars processed partially and fully sealed



Discussion of the Effect of Release of Pressure, Method of Sealing, Headspace, Time of Processing, and Filling Temperature on Loss of Liquid and Degree of Vacuum in Glass Jars

Tables 6, 8, and 10 show results on pint jars that had been processed at ten pounds steam pressure with the pressure released rapidly at the end of the process, taking about one minute to escape. Tables 7, 9, and 11 show results on jars processed at ten pounds steam pressure with the pressure released slowly at the end of the processing period. This slow release is accomplished by keeping the petcock closed and shutting off the steam inlet. This requires about ten minutes before the retort pressure decreases to zero.

Effect of Slow and Rapid Release of Pressure

A comparison of Tables 6, 8, and 10 with Tables 7, 9, and 11 shows that the rapid or slow release of steam from the pressure retort has no significant effect on the vacuum formed in the jars.

However, these data do show that out of 72 duplicate tests, 62 gave greater venting losses when the pressure was rapidly released, 4 were about the same, and 6 showed greater losses when the pressure was slowly released. Table 12 shows a tabulation of these results and Figure 1 presents a graphic description.

Therefore, it is evident that a slow release of pressure from the cooker is the preferred method in order to avoid venting losses.

Venting Losses in Fully Sealed Versus Partially Sealed Jars

In all of the 144 tests made the fully sealed jars had less venting losses than the corresponding partially sealed jars. The average loss of weight of 72 partially sealed jars was 44.6 grams whereas, for the same number of fully sealed jars the average loss was only 6.6 grams. The smaller loss of contents will leave the liquid level much higher in the fully sealed jars than in the partially sealed jars. This fact has a practical application in home canning because loss of jar liquid results in an actual food loss as well as an unattractive appearance. Furthermore, the possibility of later spoilage is increased because as the internal liquid is forced out of the jar it may carry with it particles of solid matter which get lodged between the rubber sealing ring and the lip of the jar, thus providing an entrance for spoilage organisms.

Relation of Venting Losses to Amount of Headspace

From the results in Tables 6 to 11 it seems that the greater the original headspace in the jar, the less the venting loss during processing. When the headspace was

56 c.c., the average venting loss when the retort pressure was rapidly released was almost five times as great in the partially sealed jars as when the headspace was 97 c.c. Similarly, when the retort pressure was slowly released the loss in corresponding partially sealed jars was almost three times as great. This same trend was noticeable in fully sealed jars but to a lesser degree. The loss in the smaller headspace jars differed on an average of two grams from the larger headspace jars. Fully sealed jars may, therefore, be filled to a higher level with original liquid in packing than the partially sealed jars.

Relation of Length of Process to Vent Loss

An understanding of the development of jar pressure and of retort pressure will show that the only significant difference between the two occurs when the retort pressure is being released. The pressure within the jar lags behind the retort pressure until a pressure difference occurs that is great enough to raise the cover of the jar and partially equalizes. This discharge of gases under pressure carries with it liquid from the jar thus increasing the vent loss. As the greatest release of jar pressure occurs when the retort pressure is released the length of time of the process after the maximum pressure in the jar is attained does not affect the vent loss. For example, a jar processed at 240° F. for 30 minutes would have as much vent loss as one processed for two hours at the same temperature. Tables 6 to 11 substantiate this by showing no constant difference among the vent losses of jars processed 20, 40, and 60 minutes.

It is also probable that much of the loss of liquid occurs during processing by the bubbling of contents and by internal agitation. Table 12 and Figure 1 show that the larger the headspace, the less the loss in venting confirming this belief.

Relation of Filling Temperature to Venting Losses

Filling temperature had little or no effect on the amount of liquid lost during processing. Perhaps this was due to the fact that no losses occur until the boiling point is reached and, regardless of filling temperatures, all the jars had to go through the same temperature range of 212 to 240° F. during which agitation might have occurred. Thus, provided the headspaces were constant, all the jars would undergo approximately the same vent loss.

Relation of Bail Tension to Loss of Liquid

There is a definite correlation between bail tension and loss of liquid, that is, the weaker the wire bail, the greater the venting loss. This conclusion was reached through an examination of 162 jars of asparagus all processed for 30 minutes at a temperature of 240° F. Although fully sealed while processed, there was no breakage and the loss of liquid was slight. Those jars that had the greater loss had the weaker bails. This general conclusion has been checked through measurements of liquid losses on several hundred other canned products as well. Tensions were not actually measured; they were estimated.

Associated Experiments

Does Retort Water Enter Glass Jars During Processing?

To see if there was an ingress of water from the water bath into glass jars fully and partially sealed, duplicate sets of jars were filled with clear water and sealed, one set fully, the other partially, and immersed into a water bath containing water colored with amaranth dye. After having been subjected to a boiling temperature for thirty minutes, the jars were removed from the bath. The fully sealed jars still contained the clear water but the partially sealed jars contained the brilliant red color of the water bath showing that there was a transfer into the partially sealed but not into the fully sealed jars.

In order to prove the same condition existing in pressure retort processing, enough safranine dyed water was placed in a small retort to completely cover sets of jars similar to the ones used in the water bath experiments.

In this case the pressure was brought up to 10 pounds and held there for 30 minutes. Upon removal from the retort, the partially sealed jars were strongly colored whereas the fully sealed jars contained only the original clear water. The results of this experiment were further substantiated by pressure readings during the processing of partially and fully sealed jars. There is a direct transfer of steam pressure from the retort to the inside of the partially sealed jar. This does not take place when the jars are fully sealed.

Effect of Seal on Glass Strain

As an incidental experiment, duplicate jars were filled with water of varying temperatures: 180°, 110°, and 78° F.; one set was partially sealed and the other set was fully sealed. All the jars were immersed into a boiling water bath. None of the jars broke although plunging cold jars into boiling water is not recommended as a usual procedure. Several times throughout the canning season jars of corn were removed from the processing retort and transferred after only three minutes' cooling to the refrigerator (32-40° F.) with no breakage.

Maximum Temperatures Obtained in Processed Jars

Duplicate jars were filled with water standardized at 70° F., fully and partially sealed, and then processed for 5, 10, 15, 20, and 25 minutes in a steam pressure retort. Each jar had a tested maximum recording thermometer with a temperature range of 200° to 245° F. Table 13 shows that there is no difference between the two methods of sealing on the temperature attained during processing. The maximum recording thermometer was checked by being suspended in the retort for five minutes at 10 pounds steam pressure. Upon removal it read 240° F.

These results are in accordance with Maclinn's (3) 1935 conclusive work on heat penetration of partially sealed and fully sealed jars in which he used a calibrated thermocouple.

Table 13. Maximum Temperature Attained in Pint Jars Processed at 240° F. for Varying Periods of Time

Time in minutes	Temperature in degrees F.	
	Fully sealed jars	Partially sealed jars
5	220	217
10	230	230
15	235	236
20	240	238
25	240	240

Pressures Developed in Glass Jars During Thermal Treatment

In the use of the fully sealed method the safety factor involves two phases: first, effective sterilization of the product and, second, protection of the operator from exploding glass and burns during and immediately after processing. In a previous section it has been adequately shown that both methods of sealing before processing result in high vacuums which effect a hermetic seal that will help insure the keeping quality of the jar contents. Destruction of spoilage organisms takes place during the heat treatment and so long as no bacteria, yeasts, or molds can obtain entrance into the container, the product will remain in an unchanged and edible condition.

A consideration of the second phase of the safety factor involves a study of the internal pressures developed in glass jars during processing.

Effect of Temperature Alone on Internal Pressure

In order to study separately the physical factors involved during the processing of glass jars, it was necessary to utilize some means whereby only one factor at a time caused any change. Temperature and pressure are the two main physical factors. To study retort temperatures without the influence of external pressure, an oil bath was used because oil would reach a temperature equal to that attained in a retort having ten pounds steam pressure, namely, 240° F. Venting points in experimental jars immersed in the oil bath were easily recognized by one to two millimeters fluctuations in the mercury column.

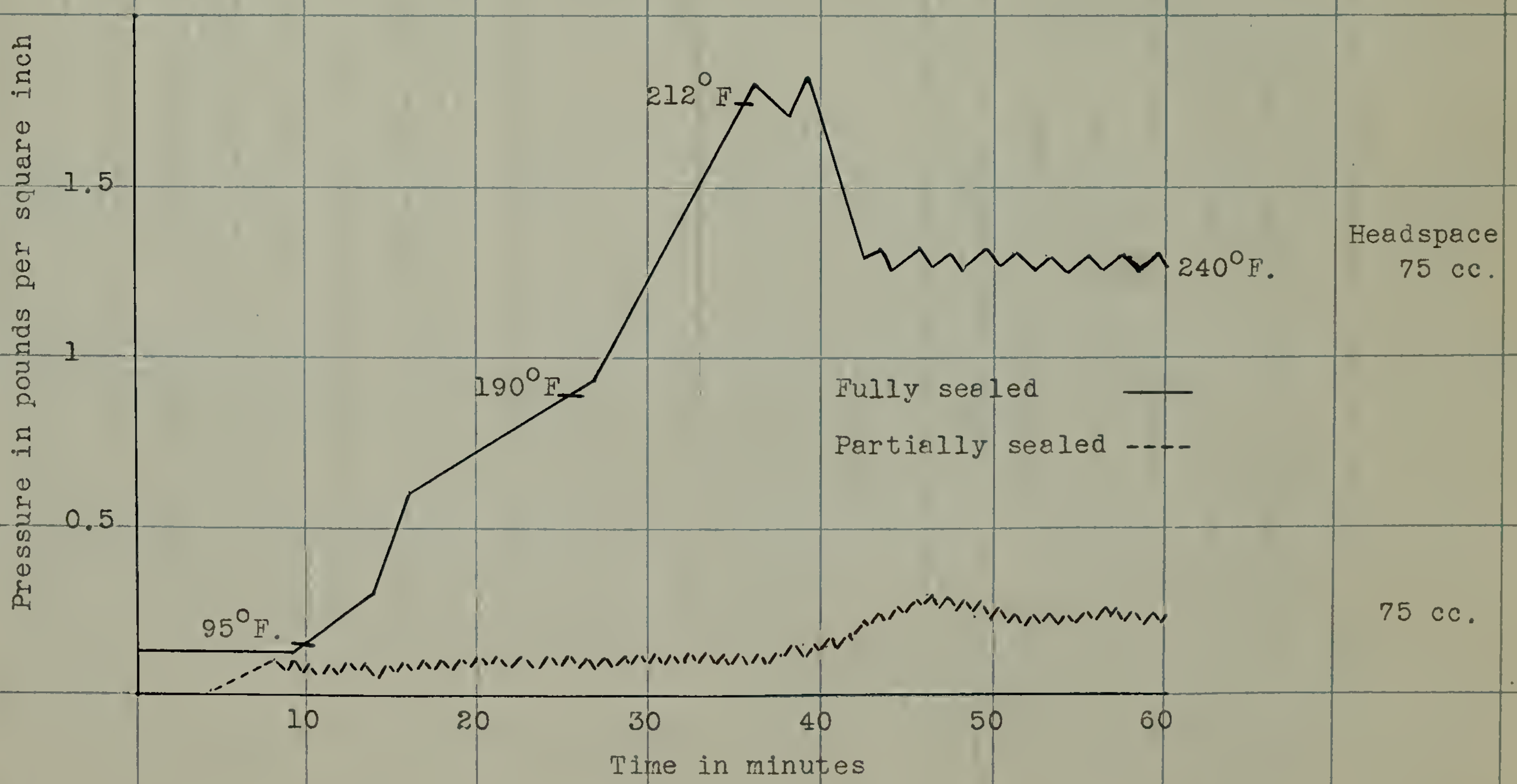
The data secured from this experiment are shown in Table 14. Figure 2 shows graphically the venting and development of pressures in these partially and fully sealed jars processed in an oil bath.

The elapsed time before venting occurred was not so important as the pressures at which venting occurred because in heating the oil care had to be taken to prevent violent agitation. The electric unit used to regulate the heat was not subject to fine adjustments.

Table 14. Pressure Developed in Partially and Fully Sealed Pint Jars Processed in an Oil Bath Through the Temperature Range of 75° to 240° F.

Pressures at which venting occurred		Time elapsing before venting occurred	
Pounds per square inch		Minutes	
Partial seal	Full seal	Partial seal	Full seal
.10	2.98	8	29
.10	1.82	8	36

Figure 2. Pressure developed in partially and fully sealed pint jars processed in an oil bath through the temperature range of 75° to 240° F.



Effect of Pressure Alone on Internal Pressures

In order to study retort pressure effects without the influence of heat, an air pressure pump was attached to the petcock of a small pressure cooker. The experimental jar with a tube leading from the cover of the cooker to the U-tube manometer was placed inside of the retort and the cover was clamped down tightly. The jar contained water at 70° F. and had one-half inch headspace. The pump was started and air flowed into the retort. Seven pounds was the maximum pressure obtainable in the cooker as read on its gauge. Jar pressure readings were made as usual on the mercury column of the manometer. Pressures obtained in three partially sealed jars were 0.68, 6.77 and 6.50 pounds per square inch respectively and for three corresponding fully sealed jars: 0.1, 0 and 0 pounds per square inch.

There was a slight water loss in the partially sealed jars but none in the fully sealed jars. The 0.68 pound per square inch rise in the first partially sealed experiment is thought to be due to the rapid increase of retort pressure which made its way into the partially sealed jar only to the extent of 0.68 pounds per square inch before the excessive retort pressure helped to seal the cover fully. On the duplicate trials with the partially sealed jars, pressure was drawn into the retort more slowly with the result that there was a corresponding rise in partial seal jar pressure and retort pressure. On duplicate trials with fully sealed jars there was no rise in jar pressure which gave further indication that the system did not leak.

Pressures Developed in Pint Jars During Thermal Treatment

Tables 15 and 16 show briefly that partially sealed jars processed in a water bath never build up any appreciable pressure. The fully sealed jars, however, show a maximum pressure of 6.19 pounds per square inch after 55 minutes in a water bath through the temperature range of 70° to 212° F. These data may be misleading in indicating that the venting of fully sealed jars does not occur until after a long heating period. This is not the case as observed in actual practice where the jars are placed in fairly hot water. Actually, venting occurs within a few minutes. (See Table 5) Repeated observations were made on jars of raspberries, blueberries, tomatoes, etc. that were fully sealed before processing in a water bath. They invariably vented in 1 to 3 minutes. Jars showing no vacuum, thereby indicating no venting, have not been found whether water bath or pressure processed. This shows that venting always occurs even when the jars are fully sealed.

Table 15. Pressures and Time-Intervals at Which Venting Occurs in Pint Jars Processed in a Water Bath Through a Temperature Range of 70° to 212° F.

Jar No.	Pressure			Time elapsing before venting	
	Partially sealed	Fully sealed		Partially sealed	Fully sealed
	Pounds per sq. inch	Pounds per sq. inch		Minutes	Minutes
1	.14	2.42	(180° F.)	6	21
2	.04	3.74	(186° F.)	6	23.5
3	.08	4.64	(208° F.)	6	31.
4	.06	6.06	(212° F.)	9	32.5
5	.23	5.88	(212° F.)	10	43.
6	.04	4.45	(196° F.)	6	39.
7	.10	5.16	(212° F.)	8	53.
8	.09	6.19	(212° F.)	6	55.
Mean	.0975	4.82		7	37

Table 16. Pressures and Time-Intervals at Which Venting Occurs in Pint Jars Processed in a Water Bath Through a Temperature Range of 190° to 212° F.

Jar No.	Pressure		Time elapsing before venting	
	Partially sealed	Fully sealed	Partially sealed	Fully sealed
	Pounds per sq. inch	Pounds per sq. inch	Minutes	Minutes
1	.135	3.23 (200° F.)	4	9
2	.10	2.61 (195° F.)	4	5
3	.12	2.70 (196° F.)	4	5.5
Mean	.118	2.84	4	6.5

Although the experimental jar apparatus was used to secure the results tabulated in Table 16, the data shown here, in addition to that of Table 1, demonstrate more clearly the slight margin of difference of results when both methods of sealing are used. As the venting is the main cause of the vacuum, if both, fully and partially sealed pint jars with the same headspace vent at about the same time and to the same degree, they will both have the same amount of vacuum when the jars are cooled after processing.

The maximum pressure measured in a glass jar during processing in a water bath was 6.86 pounds per square inch.

Although the pressure developed in fully sealed jars processed in a water bath is from two to six pounds higher than that developed in partially sealed jars, there has been no experimental or practical evidence yet to show that this pressure is in any way dangerous or likely to cause an explosion of the jar. By the time the jar is cool enough to remove from the processing tank, the pressure has been diminished to such an extent that the remaining pressure is not sufficient to cause any damage even if the jar should crack because of a flaw.

Figures 3 - 8 compare graphically the pressures developed in partially and fully sealed jars processed in boiling water and under pressure. Pint jars filled with water were used in these determinations. Because the strain of processing might lessen the tension on the wire bail, a new bail was used for each determination in addition to a new rubber ring. As the pressure of gas at the laboratory was not constant, electricity was used as the source of heat. The heating unit was so regulated that maximum heat was available at the start of the processing.

Discussion of Water Bath Processing

From Figures 3 and 4 which show the development of pressure in water bath processing one might conclude that a jar fully sealed vents only once or twice during the whole processing period. This is not the case for, in water bath processing one is able to see the gas bubbles escape when the jar first vents. This venting continues steadily until the processing period is completed.

In both of the figures on water bath processing only one curve is drawn to designate the pressure developed in partially sealed jars. This curve is typical for all jars sealed partially and processed in a water bath regardless of headspace. Headspace is also of little consequence in fully sealed jars. The amount of pressure developed would depend more on the condition of the rubber ring, tension of the bail, and the way the cover fits the jar.

Figure 3. Pressure developed in pint jars processed partially and fully sealed in a water bath through the temperature range of 70° to 212°F.

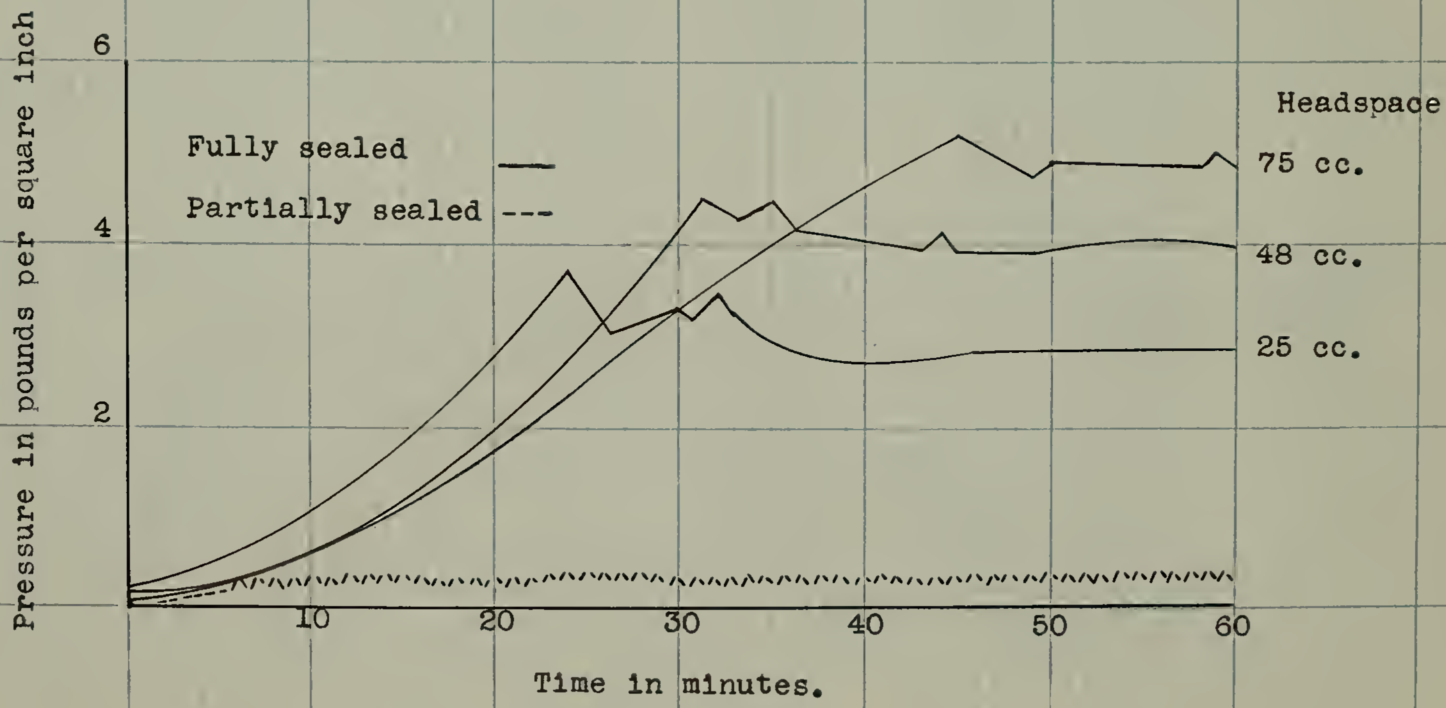
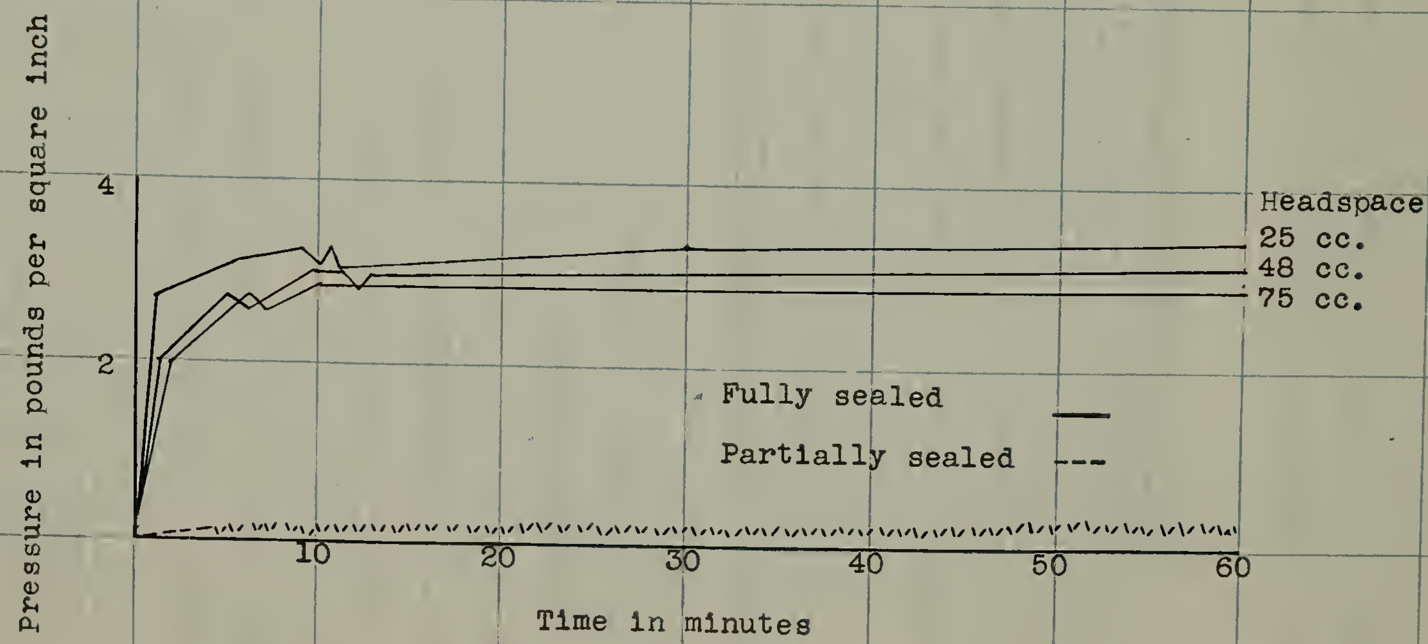


Figure 4. Pressure developed in pint jars processed partially and fully sealed in a water bath through the temperature range of 190° to 212°F.



An increase in the filling temperature and in the initial temperature of the water bath would only serve to cause a more rapid rise of internal pressure as shown in Figure 4.

Discussion of Pressure Cooker Processing

While the fully sealed method was found desirable to use in water bath processing, the advantages of the method were still more noticeable in pressure processing. It is in the latter method of preservation that the largest liquid losses are encountered in the final product. If a jar is partially sealed, placed in a retort, and processed at ten pounds steam pressure, the jar will also contain ten pounds steam pressure. When the pressure is released from the retort, the jar excess pressure will also be equalized. Thus, liquids and vapors are lost to such an extent that there is a noticeable loss in volume of the contents of the cooled jar. Although a fully sealed jar processed under similar conditions will also develop an internal pressure of approximately ten pounds per square inch it will release this pressure so slowly, upon release of retort pressure, that there will be practically no loss of liquid from the jar contents.

It was to prevent loss of contents and the poor appearance of partially sealed jars that the fully sealed method was originally tried for pressure processing. And, yet, with the improved appearance there is no sacrifice of keeping quality. The internal changes occuring during the processing by both methods are practically the same. This is clearly shown in Figures 5 to 8.

Figure 6 is especially interesting in that it shows a partially sealed jar reacting like a fully sealed jar due to a rapid rise in retort pressure, perhaps in addition to a faulty cover seat, effecting the seal. Ordinarily, partially sealed jar pressures rise and fall with the retort pressure.

From these figures one can also see that after the petcock is closed each jar apparently vents one or two times. This was due to fluctuations of retort pressure beyond the control of the operator. A decrease or an increase of as little as a quarter pound per square inch in the retort would make a noticeable corresponding change in the jar pressure. Theoretically, if a retort pressure did not fluctuate at all, but rose constantly to the desired pressure and stayed there, the fully sealed jar would not vent until the retort pressure was released. However, this is improbable in actual practice for even automatically controlled retorts shut off at regular intervals long enough for venting to take place during the processing period.

Figure 5. Pressure developed in pint jars processed partially and fully sealed in a pressure cooker at 240° F. Filling temperature 70° F.

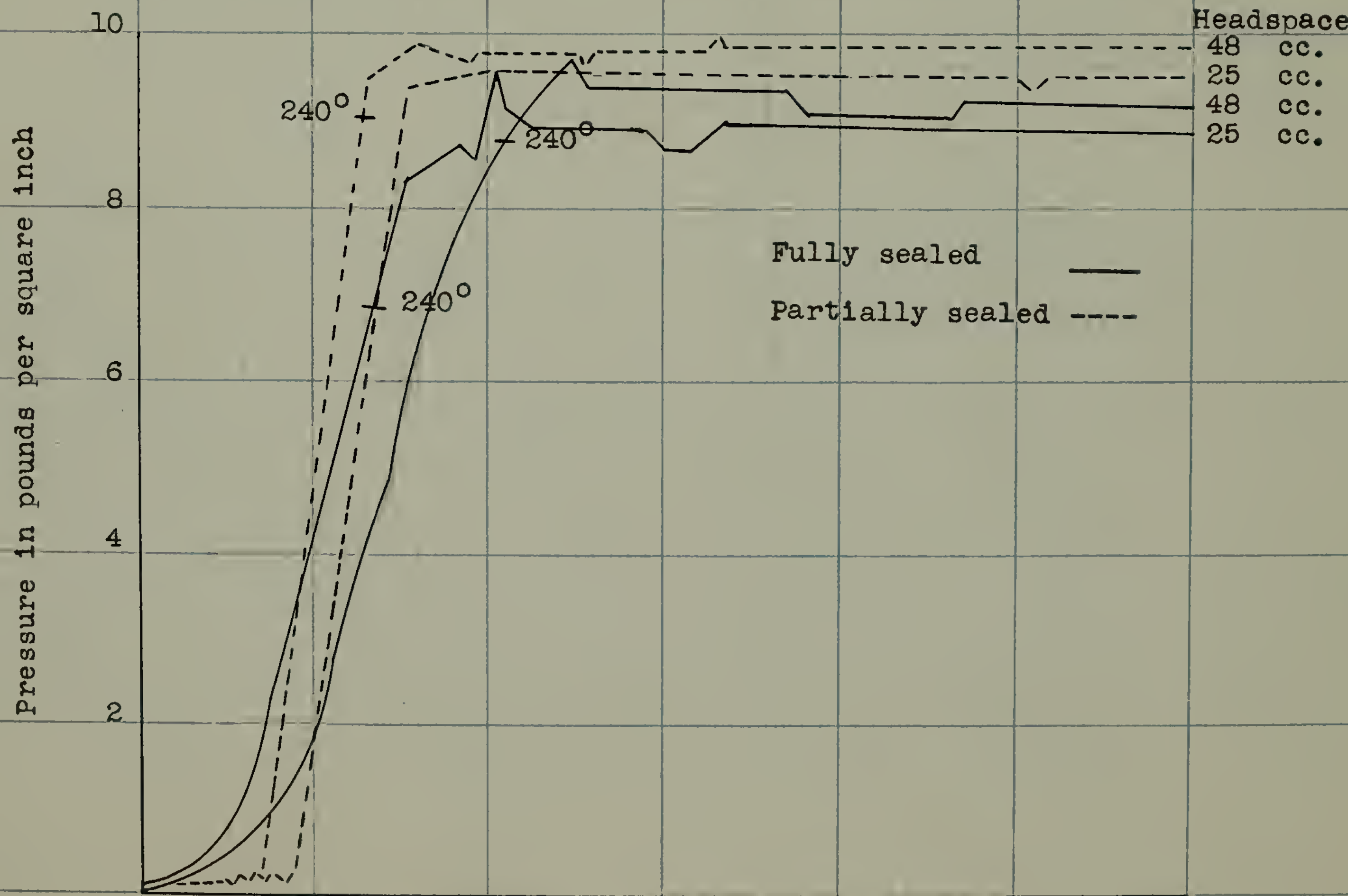


Figure 6. Pressure developed in pint jars processed partially and fully sealed in a pressure cooker through a temperature range of 70° to 240° F.

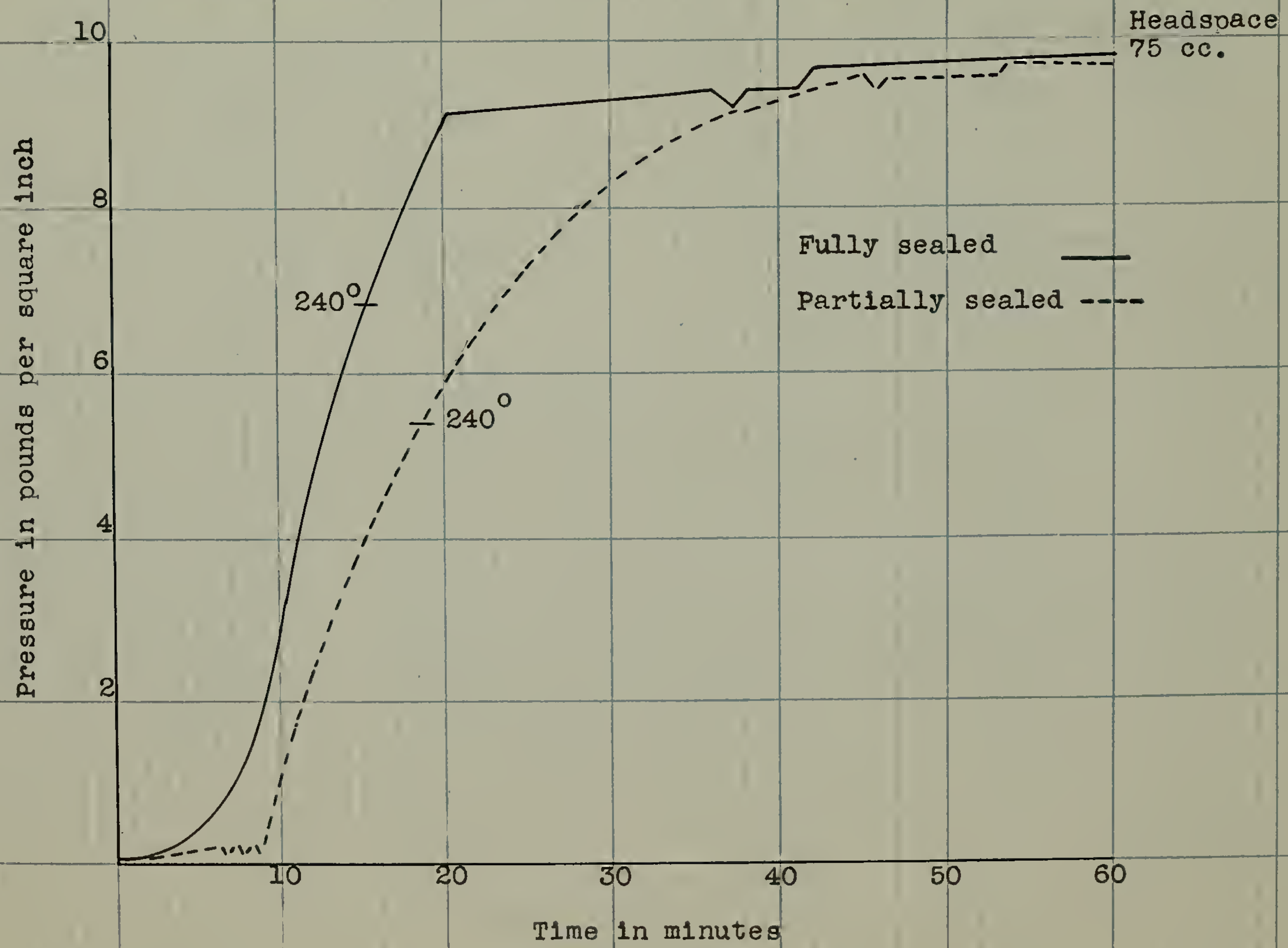


Figure 7. Pressure developed in pint jars processed partially and fully sealed in a pressure cooker at 240° F. Filling temperature 180° F.

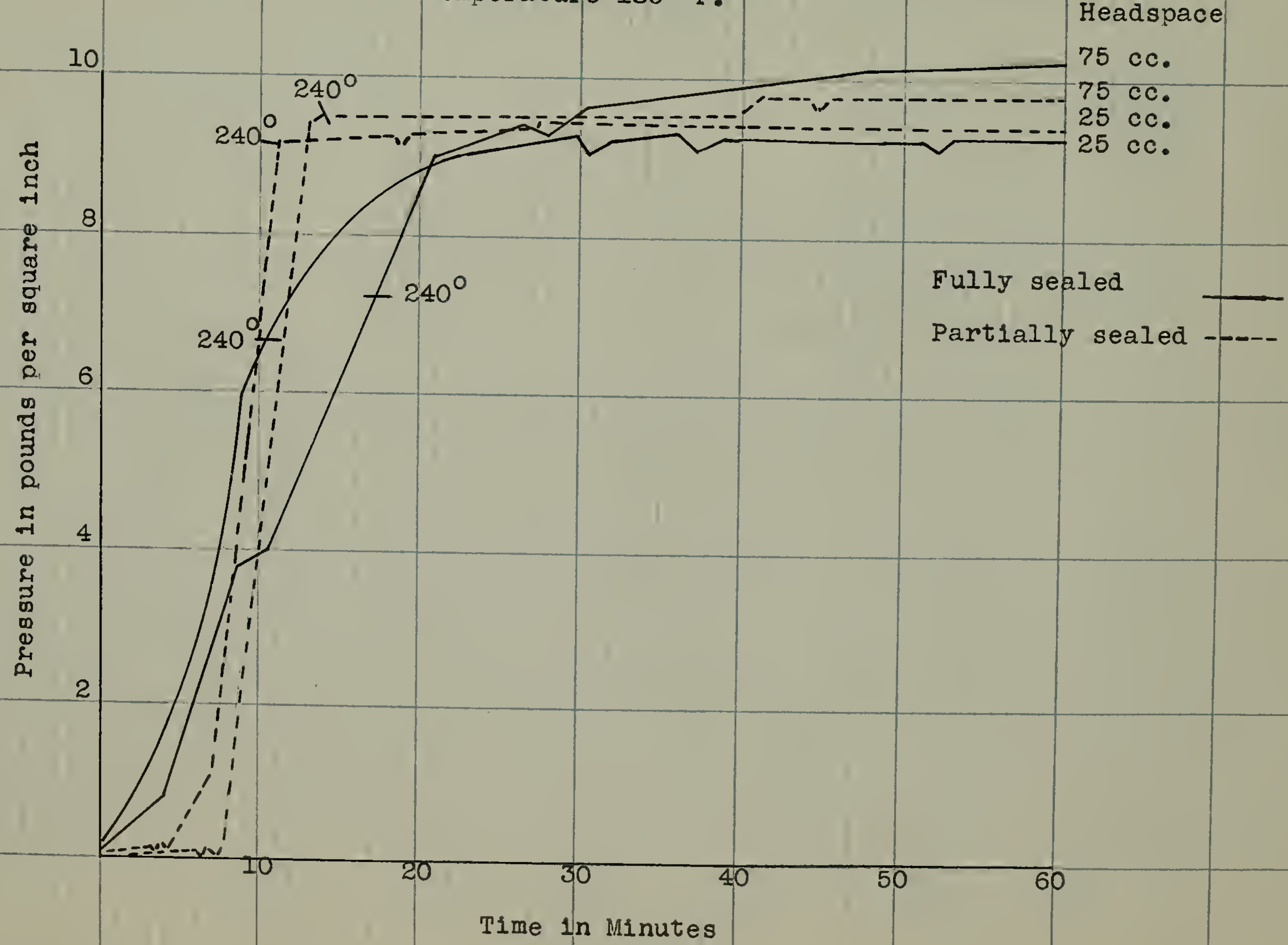
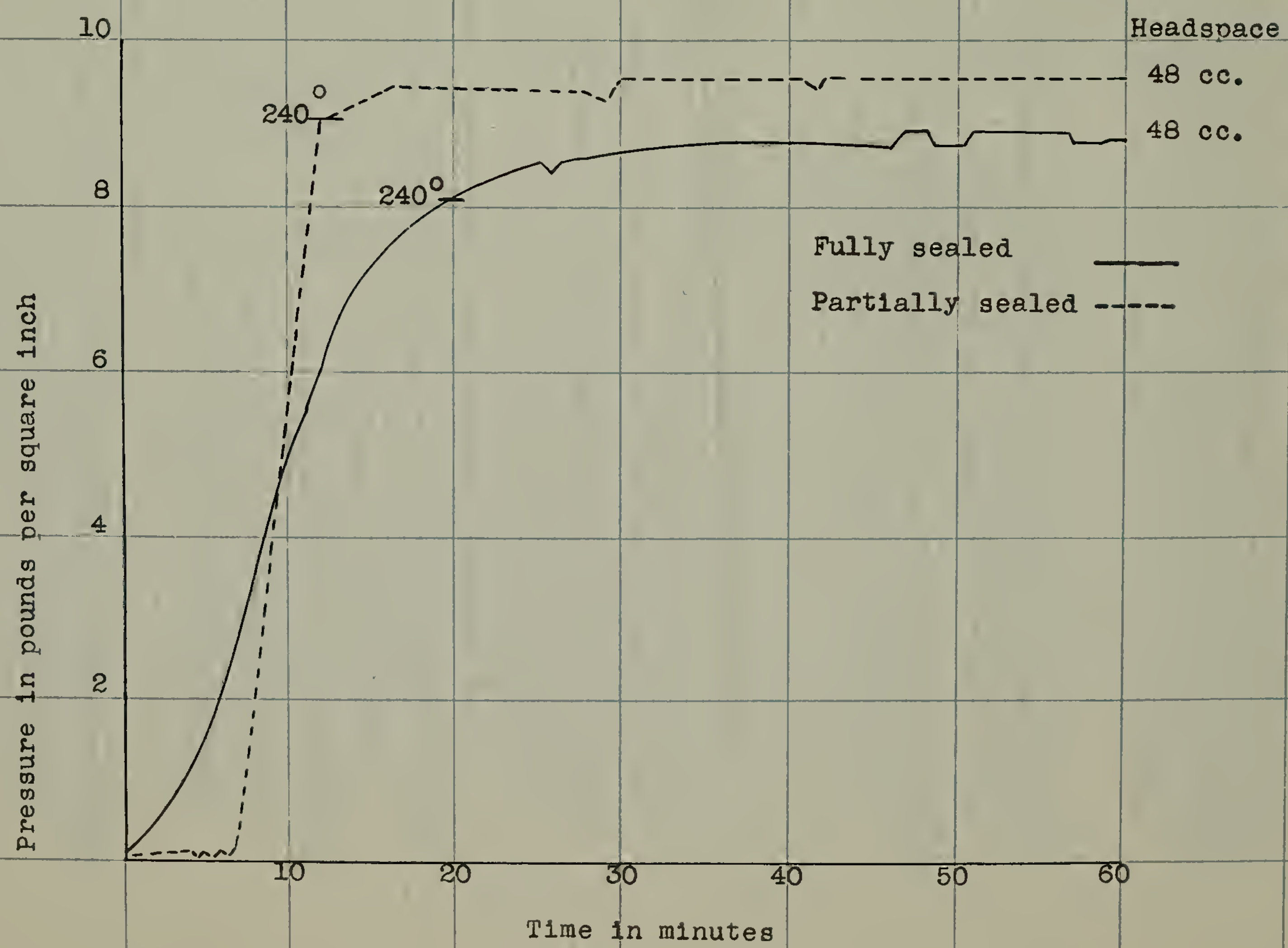


Figure 8. Pressure developed in pint jars processed partially and fully sealed in a pressure cooker at 240° F. Filling temperature 180° F.



Fully sealed jars are slightly slower in attaining retort pressure than partially sealed jars but in cooling, the former release their pressures slower than do partially sealed jars thus equalizing the time held at a definite pressure.

Differences in headspace and in filling temperatures make little difference in the pressures developed. The extent of pressure created in the jar is entirely dependent on the pressure developed in the retort, regardless of the type of seal.

COOPERATIVE CANNING EXPERIMENTS WITH HOME CANNERS

During July and August of 1935 new all-glass jars were distributed to experienced home canners of Western Massachusetts with the stipulation that all processing of these jars be done with the bail tightened i.e. fully sealed. Each cooperator was also provided with new rubber rings, a set of instructions and precautions, a book of canning recipes and a form sheet to be returned to our laboratory. This form sheet was to contain data on loss of liquid and breakage during the process period. See sample data sheet.

The tabulated data of this report are shown in Tables 17 and 18 and represent the information obtained from 87 per cent of these cooperators.

Data Sheet

Cooperator's Name ______________________________

Product	No. of Jars	Process		Breakage	Loss of Liquid			
		Time	Temp.	No. of Jars	None	Slight $0-\frac{1}{2}$"	Moderate $\frac{1}{2}$"-1"	Marked over 1"

The survey was successful and the cooperators, judging from notations written on the report sheets, seemed pleased with the new method of fully sealing the jars before processing. Several remarked that they had been using this method in a limited way with complete success but were uncertain as to its safeness.

Much valuable information was obtained from work done at the Industrial School for Boys at Shirley, Massachusetts and at the Industrial School for Girls in Lancaster, Massachusetts. The canning work at both of these institutions was headed by Dr. W. W. Stuart and Marion A. Taylor, respectively, of the Massachusetts State College.

There was no serious breakage nor loss or liquid in any one case. The most dangerous breakage reported was that of a jar which "cracked with some violence." Usually cracked jars can be lifted out of the retort or water bath in one piece. One cooperator inadvertently permitted the pressure in the cooker to rise to thirty pounds. Upon opening the cooker she found that there was neither breakage nor loss of liquid in the jars of that batch. It is interesting to note that the percentage of breakage in water bath processing and in pressure cooker processing is about the same, e.g. one per cent.

Although cautioned not to fully seal glass jars in oven canning, one cooperator did process 14 quarts of tomatoes for 90 minutes at 275° F. in an electric oven. Although no difficulties were encountered in this instance, it is still deemed inadvisable to use oven canning, particularly for fully sealed jars.

Meat products and corn caused the most difficulty in canning, both in the laboratory and afield. It was in the canning of these products that reports showed that several jar rubbers were pushed out beyond the point of effective sealing. This was true mainly in the case of meat where the fat tends to grease the rubber ring and permits the internal pressure to push it out easily causing a "blown" condition and a faulty seal. Partial sealing does not prevent this undesirable condition. A very large headspace, approximately one or two inches, lessens the extent of lubrication by the fat and largely prevents the blowing of rubber rings. It might be advisable to use a specially hardened rubber ring where warranted by sufficient meat canning. In several instances jars of corn showed marked loss of liquid. However, in the laboratory canning of corn, care was taken to keep the sealing rim of the jar free of corn particles and good results were obtained.

Of the 16,588 jars packed, fully sealed, cooperators reported no noticeable loss of liquid in 85.5 per cent, slight loss in 10.4 per cent, moderate loss in 2.2 per cent and marked loss in 0.6 per cent.

The results of this practical field test of the fully sealed method of processing substantiate the results of the laboratory tests and show that the method recommended is a distinct improvement over the partially sealed method of processing as formerly advocated.

Table 17. Results of Reports from Home Canners Using the Fully Sealed Method of Canning

Number of Cooperators	64
Reports returned	56 or 87 per cent

Jars issued:

Pints	2,772
Quarts	2,640
½ Gals.	174
	5,586 jars

Issued jars reported:			Additional jars reported:
Pints	2,338		
Quarts	2,148		2,404
½ Gals.	174		9,524
Total	4,660	(84 per cent)	11,928
	11,928		
Total jars reported	16,588		

Breakage:

Jars	135 or 0.81 per cent
Covers	55 or 0.33 per cent
Total	190 or 1.14 per cent

Pressure processing breakage:	21 or 0.91 per cent
Water bath breakage	169 or 1.18 per cent

2,287 jars were pressure processed - 10 pounds, 240° F.
14,287 jars were water bath processed - 212° F.
14 jars were electric oven processed - 275° F.

16,588

Loss of liquid:

	None	Slight	Moderate	Marked
Pints	~~1,747~~ 1901	494	169	82
Quarts	2,850 2696	1,176	172	22
Half Gals.	9,597	61	28	0
Total	14,194	1,731	369	104
Per cent	85.5%	10.4%	2.2%	0.62%
Total	16,398			

Table 18. Products Packed by Cooperators

Applesauce
Beef broth
Beans - lima, shelled,
string
Beets
Pickled beets
Blackberries
Blueberries
Broccoli
Carrots
Cauliflower
Cherries
Corn
Chili sauce
Currents
Fish
Fish flakes
Fruit juices
Fruit syrups
Grape ade
Grape sauce
Grape juice
Ham
Hamburg
Lamb chops
Meat
Mustard pickle
Mushrooms
Peaches
Pears
Peppers
Pepper relish
Piccalilli
Pimientos
Pectin
Plums
Raspberries
Raspberry jam
Roast pork
Sausage
Squash
Sweet mixed pickle
Tomatoes
Tomato juice
Tomato paste
Tomato puree
Veal
Vegetable soup

5,565	jars tomatoes and tomato products
2,584	jars beans - shell, lima and string
1,924	jars peaches
786	jars beets
720	jars corn
11,579	or 70 per cent of the products packed.

GENERAL SUMMARY

1. An apparatus for the determination of pressures developed in all-glass jars during processing is described. The principle feature of this apparatus is an aluminum cover duplicating a glass cover.

2. Methods were developed to determine the amount of headspace under the cover when the cover is on the jar. Also an instrument was made for securing uniform headspace rapidly.

3. The vacuums formed in glass jars processed in the fully sealed condition are high, averaging well over 20 inches of mercury.

4. In a water bath at a temperature of 180° F. or above most fully sealed jars vent within three minutes. Partially sealed jars vent in about one minute.

5. Fully sealing, slow release of pressure, and large headspace tend to decrease the loss of contents in venting in pressure processed jars.

6. Fully sealing prevents entrance of water or steam from the processing tank or pressure cooker into the glass jar.

7. In water bath processing the pressure developed in partially sealed jars is negligible. Fully sealed jars develop from 2 to 6 pounds pressure. Glass jars are strong enough to withstand this pressure without bursting.

8. In pressure processing the pressures developed in partially and in fully sealed jars are similar, being within one pound of the retort pressure. The fully sealed jar takes a longer time than the partially sealed jar to attain this pressure. Usually, the rise in pressure of partially sealed jars corresponds to the rise in pressure in the retort.

9. A practical survey of the use of the fully sealed method by 64 home canners who used a total of more than 16,500 jars to pack 50 different products proves definitely the practicability of the use of this method in canning with all-glass jars. Of the jars packed, 85.5 per cent had no noticeable loss of liquid. Tomatoes, beans, peaches, beets and corn constituted the bulk of the products canned.

10. Some slight difficulty in the canning of fatty meats and corn in both partially and fully sealed jars which results in an expanded condition of the rubber ring may be overcome by the use of a large headspace and extra care in filling the jar.

CONCLUSION

As a result of a two year investigation of the vacuums and internal pressures of all-glass canning jars during processing and of practical cooperative experience involving over 16,500 all-glass jars, 50 canned foods, and 60 home canners, it is considered advisable to fully recommend sealing the jar by tightening the wire bail previous to thermal treatment (processing).

This method decreases markedly the liquid losses from jars during processing, improves their appearance, saves time, makes unnecessary the handling of the hot jars after processing and has no effect on either breakage or spoilage.

BIBLIOGRAPHY

1. Clark, E. D., Clough, R. W. and Shostrom, O. E. 1923. Function of vacuum in canned salmon. Reprinted from the Pacific Fisherman. May, June and July 1923.

2. Ford, K. L., 1930. The rise of the glass container. Glass Container, 9, No. 3, 5-7, 38.

3. Maclinn, W. A., 1935. Some internal physical conditions in glass containers of food during thermal treatment.

4. Maclinn, W. A. and Fellers, C. R., 1936. Vacuum determinations in all-glass canning jars. Food Research 1, 41-44.

5. White, H. E., 1930. The closure is rarely at fault. Glass Container, 9, No. 3, 11, 26-28.

ACKNOWLEDGMENT

To Dr. C. R. Fellers of the Department of Horticultural Manufactures and to the Hazel-Atlas Glass Company acknowledgments are made for their advice and assistance throughout the course of this investigation.

Thanks are also extended to Professors W. W. Chenoweth, M. J. Mack, and Dr. L. A. Bradley for their aid as an advisory committee.

Valuable data would not have been secured had it not been for the many home canners who cooperated with the author.

Approved by

C. R. Fellers

M. J. Mack

Leon A. Bradley

Graduate Committee

Date May 4, 1936