THE EFFECTS OF CONDITIONING, TOP LOADING, AND IMPACT ON RELEASE TORQUE

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ABSTRACT

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RELEASE TORQUE

by Ronald Walter Horiszny

This investigation was undertaken to determine the effects of three primary variables on the release torque of screw caps on glass bottles. An extensive literature search indicated that very little was known about the effects of different variables on release torque. Interviews, however, determined that a great deal more was known than has been made public on the subject.

The three variables tested were storage conditions, top loading, and impact on the top of the container. Storage conditions of 40°F., ambient humidity; ambient room temperature and humidity; and 100°F., 90 to 95% relative humidity were tested for both five and ten day storage periods. Immediate release torque was also checked. The other two primary variables investigated were the effects of a 200 pound top load and the effects of both 1 foot-pound and 2 foot-pound impact shocks.

The test results indicate that, in general, storage at any of the three conditions causes metal caps to lose torque. Storage at 40°F. or at room temperature increases the release torque of phenolic caps, but high temperature and humidity tend to decrease it. Top loading and impact were also found to decrease the torque retention of screw caps.

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By

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R. W. H.

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INTRODUCTION

The purpose of this study was to determine the effect of certain storage conditions, top loading, and impact to the container top, on the release torque of screw caps on glass bottles. Interviews (1,2,3) with people in the field of packaging indicated that these areas of testing, especially the top loading and impact tests, would be the most interesting to the glass and closure industry. The reason for this situation is that not much work has been done in these two areas, and none of it has, as yet, been published. In fact, very little has been published concerning storage conditions and release torque either.

Three storage conditions were used, each one for both five- and ten-day periods. The conditions were 40°F. with ambient humidity, approximately 70°F. with ambient humidity, and 100°F. with 90 to 95% relative humidity. The top load checked was 200 pounds and the impacts used were equal to 1 foot-pound and 2 foot-pounds.

An immediate release torque experiment was performed also, and the above tests' comparisons with it and with each other are analyzed in this thesis.

BACKGROUND

Not a great deal has been published on the subject of release torque. Most of the articles turned up by a literature search were of a practical or production nature rather than reports of experimental findings. Probably the main reason for this is that most of the research in this area has been done by the glass and closure manufacturers, and the highly competitive packaging field causes them to closely guard their findings.

Also, the articles tended to be general rather than specific - so two of them are reviewed here to present a background on release torque. In providing this background material, information from articles (4) and (5) was combined and revised to present a more complete picture.

First of all, it is pointed out that while torque for packaging is the force required to apply a cap to a container or to remove it, torque to a consumer is merely the effort needed to get a top off. This means that a packager must select an application torque which will insure the desired amount of protection to the product, but won't make it too difficult for the consumer to open the container.

The articles agree that the main factors affecting torque are the product, the cap, the cap liner, the container, time cycles, and storage conditions.

Product considerations involved, besides whether the product reacts with the cap or liner, are whether it needs to be kept within certain moisture content ranges, or just in the container. Important cap factors include the material it is made from, its dimensions, and its thread design. The item about liners which is most important to torque is the resiliency of the liner material, for generally, the more resilient the liner, the less application torque is needed to properly maintain an effective seal. Thread design, diameter, and smoothness of finish are the essential traits of the container that influence torque.

Other factors mentioned as influencing release torque are lubricants used on the cap, product being spilled on the bottle threads, pressure on the top of the cap during application, and compression set of liners.

EXPERIMENTAL PROCEDURE

SAMPLE CONTAINERS

The bottles used in the testing were of the same volume (30 cubic centimeters), but of two different finishes: 20-405 and 28-405. Finish refers to the size and type of closure means. The means in this case are screw threads - one with a 20 millimeter maximum thread dimension and the other with one of 28 millimeters.

Both types of bottle were amber glass. The 20-405 bottle had an overall height of 2-7/8 inches and an outside diameter of 1-3/8 inches. The 28-405 bottle was 2½ inches high and had an outside diameter of 1½ inches (see Figure 1).

The screw caps used were caps manufactured to fit the bottles used. Both tin-plated steel and black phenolic caps were tested. The metal caps were white enamel coated on the outside. All caps tested were lined with 0.035 inch pulp/vinylite lubricant finish liners. See Figure 1, also, for a visual comparison of the screw caps.

All of the bottles and screw caps used were manufactured by Owens-Illinois, and were supplied for testing by them, or by Eli Lilly and Company.

CONDITIONING

The bottles and caps were stored together in the same area of a room for at least two weeks prior to filling and testing, in an

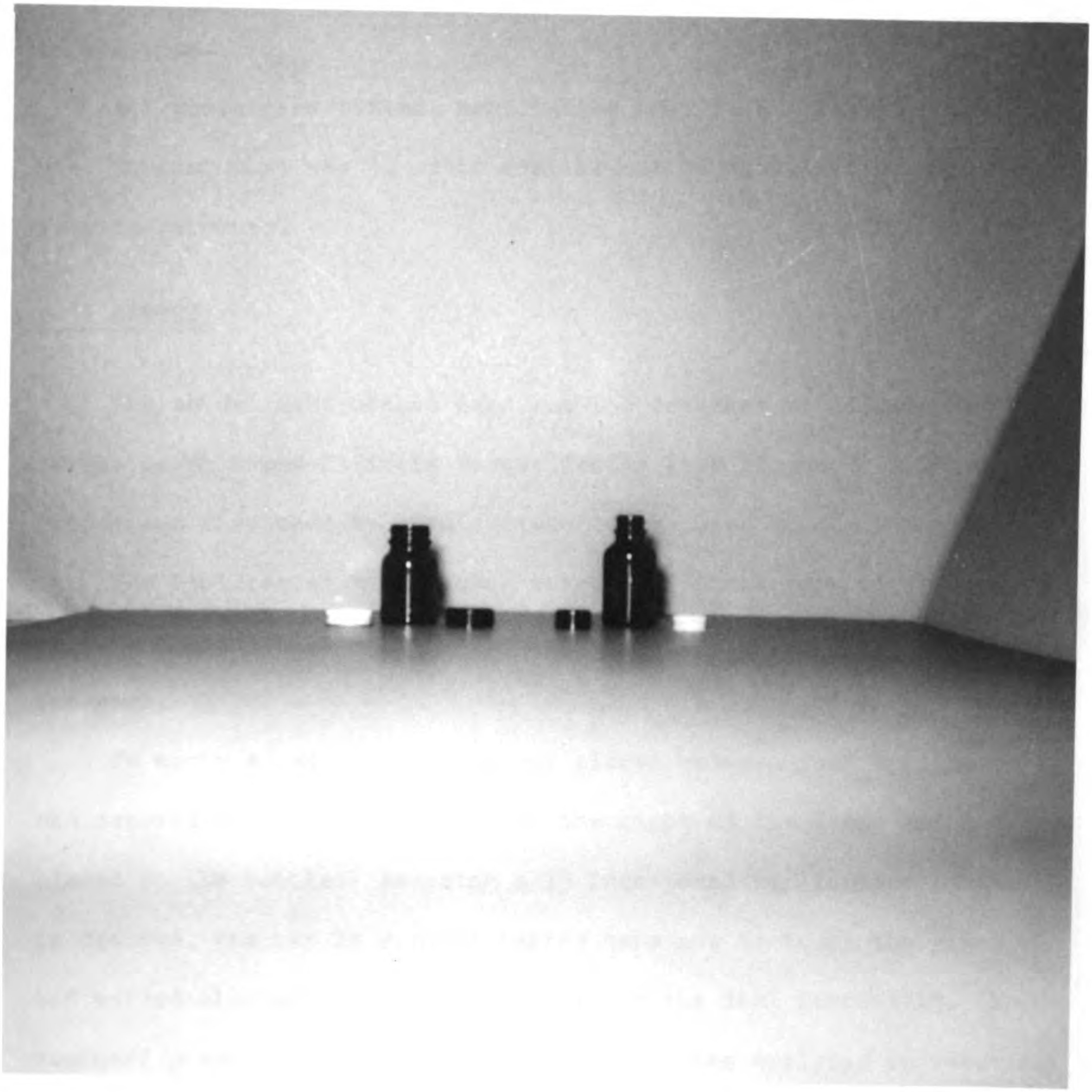

FIGURE 1

Sample screw caps and bottles

attempt to eliminate any variations that might be caused by unequal storage conditions. There was no attempt to control the conditions in the room.

All containers tested, were tested when full. The "product" used in each case was 30 cubic centimeters of distilled water at room temperature.

TEST METHOD

The actual test method used was the measurement of release torque on an Owens-Illinois Torque Tester (see Figure 2). This device was also used to regulate the torque used to apply the caps.

The application and release torques of screw caps were measured in inch-pounds and the torque tester used read up to 25 inch-pounds for each.

To apply a cap, the bottle was placed between four upright pegs and secured by turning the knob at the right of the disk, and the cap placed on the bottle. Assuming a 15 inch-pound application torque is desired, the cap is grasped taking care not to touch the glass, and turned clockwise until the pointer on the dial reaches 15. No downward pressure should be put on the cap when applying or removing it.

Release torque is measured in the same manner except that the cap is turned counter-clockwise and the pointer must be watched carefully in order to note the highest point reached. In this investigation, readings were taken to the nearest half inch-pound, although the dial is calibrated only in whole numbers.

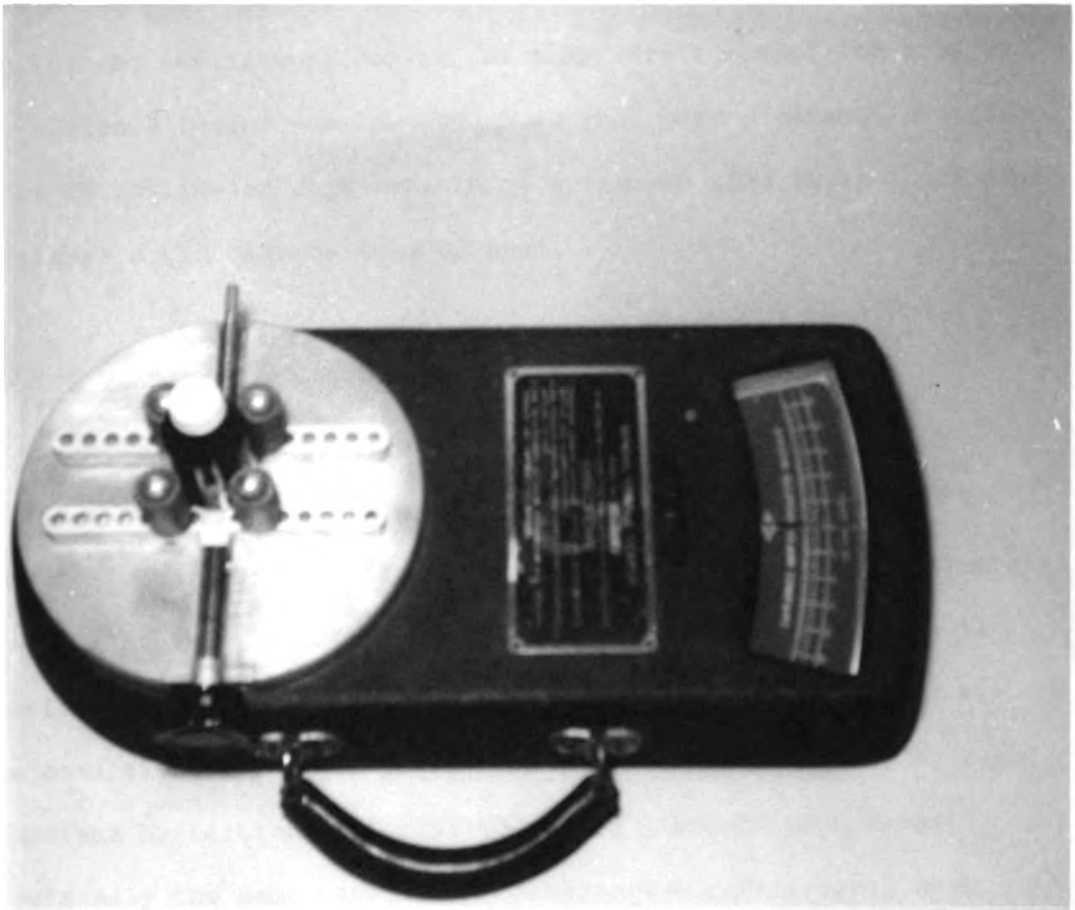

FIGURE 2

Owens-Illinois Torque Tester ready for testing

In the case of the 20 millimeter caps, a pair of pliers with rubber covered jaws (to prevent damage to the caps) was used to grasp the cap during application, as they were too small to hold by hand. Release torque was low enough so that pliers weren't necessary, and the 28 millimeter caps were large enough so that their application and release could both be done by hand.

VARIABLES TESTED

Three storage conditions were tested: Condition 1 was 40°F. and ambient humidity, Condition 2 was room temperature (approximately 70°F.) and ambient humidity, and Condition 3 was 100°F. and 90 to 95% relative humidity. Condition 3 was chosen to represent an extreme condition, and it is cited in Package Engineering (6) as such. The ambient humidities of Conditions 1 and 2 should experience approximately the same variations, because the refrigerator used for Condition 1 was in the room used for Condition 2. This room was the same one that the bottles and caps were stored in prior to testing.

Condition 3 was obtained in a Vapor-temp Relative Humidity Chamber, and the humidity did vary between 90% and 95% although it was set for about 93%.

Bottles were filled in groups of ten, each group having caps applied and being placed under its particular storage condition before the next group was filled.

Ten each of the metal and black phenolic capped bottles were stored for five days under each of the three conditions. Ten of each were also stored for ten days under each condition. The above storage lots were performed for both the 20-405 and the 28-405 size bottles. The 20 millimeter size caps were put on with an application torque of 10 inch-pounds, and the 28 millimeter caps with 15 inch-pounds. These application torques were chosen because they are mid-points of application torque ranges recommended in the manual for torque testers (6) for caps of these particular sizes. The range suggested for 20 millimeter caps is 8 to 12 inch-pounds, and that for 28 millimeter caps is 12 to 18 inch-pounds.

A new bottle and a new cap were used for each sample, with no cap or bottle being used twice. As the groups of bottles were put into their respective storage conditions, the time of day was noted so that they could be conditioned as nearly as possible to exactly a five or ten day period. No group deviated from its schedule by as much as 30 minutes. At the end of the storage period the bottles were removed by groups, and their release torque measured and recorded.

An immediate release torque test was also performed for each of the four caps (metal and phenolic 20 millimeter, and metal and phenolic 28 millimeter). In this test, ten bottles were filled as a group and then they were capped with an application torque of either 10 or 15 inch-pounds, depending on their size. Immediately after the tenth bottle was capped, the first bottle was checked for release torque. The nine remaining bottles were then checked in the same order in which they had been filled. Not more than five minutes elapsed between the time the first bottle was capped and the time that the tenth bottle was opened and its release torque recorded.

The second variable investigated was top loading. For this test, filled, capped bottles were top loaded to 200$\pm$5 pounds in a National Forge and Ordnance Compression Tester (see Figure 3) at a platen speed of one-tenth of an inch per minute. The 200 pound load was suggested in the interview with Owens-Illinois personnel (3) as a realistic load, because the stacking of pallet loads six or seven high in warehouses may create loads considerably higher than 200 pounds on the lower bottles.

The first step in this test was to fill a group of ten bottles with 30 cubic centimeters of distilled water each. These ten bottles were then capped with an application torque of either 10 inch-pounds in the case of the 20 millimeter metal caps, or 15 inch-pounds for the 28 millimeter metal caps. After the tenth bottle was capped, the first bottle was top loaded and then immediately taken out of the compression tester and checked for release torque. The top loading and checking of bottles two through ten in the same manner, followed directly. These steps were repeated on a second group of ten for each cap, to give a total of 20 trials for each of the four caps.

The third variable investigated was impact to the top of the bottle. This test was also suggested in the Owens-Illinois interview (3) mentioned above. The impact appartus shown in Figure 4 is simple. Its purpose was merely to direct the steel ball used tc impart the impact so that it would hit the cap directly in the center. The ball

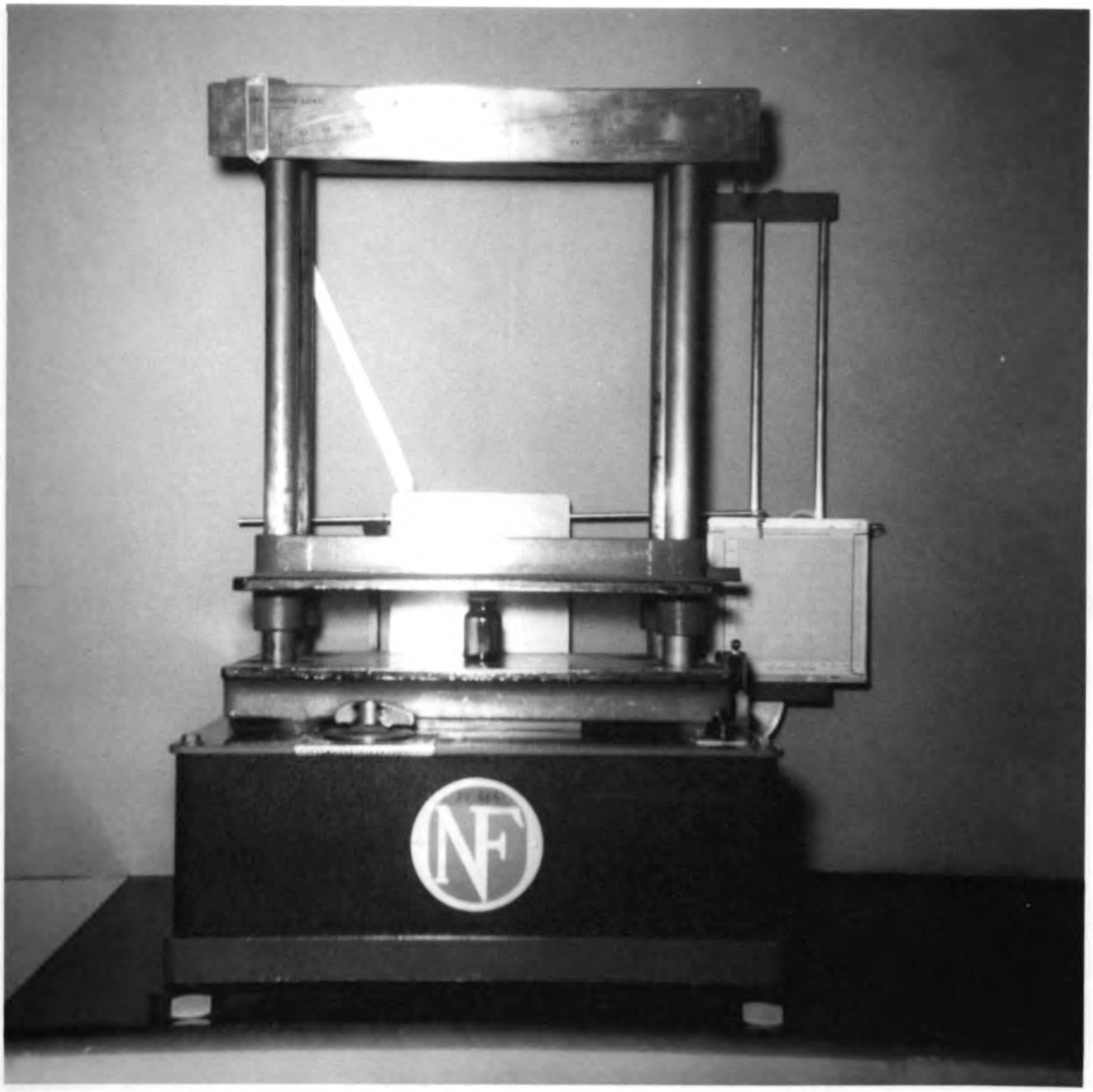

FIGURE 3

National Forge and Ordnance Compression Tester

ready to top load a sample

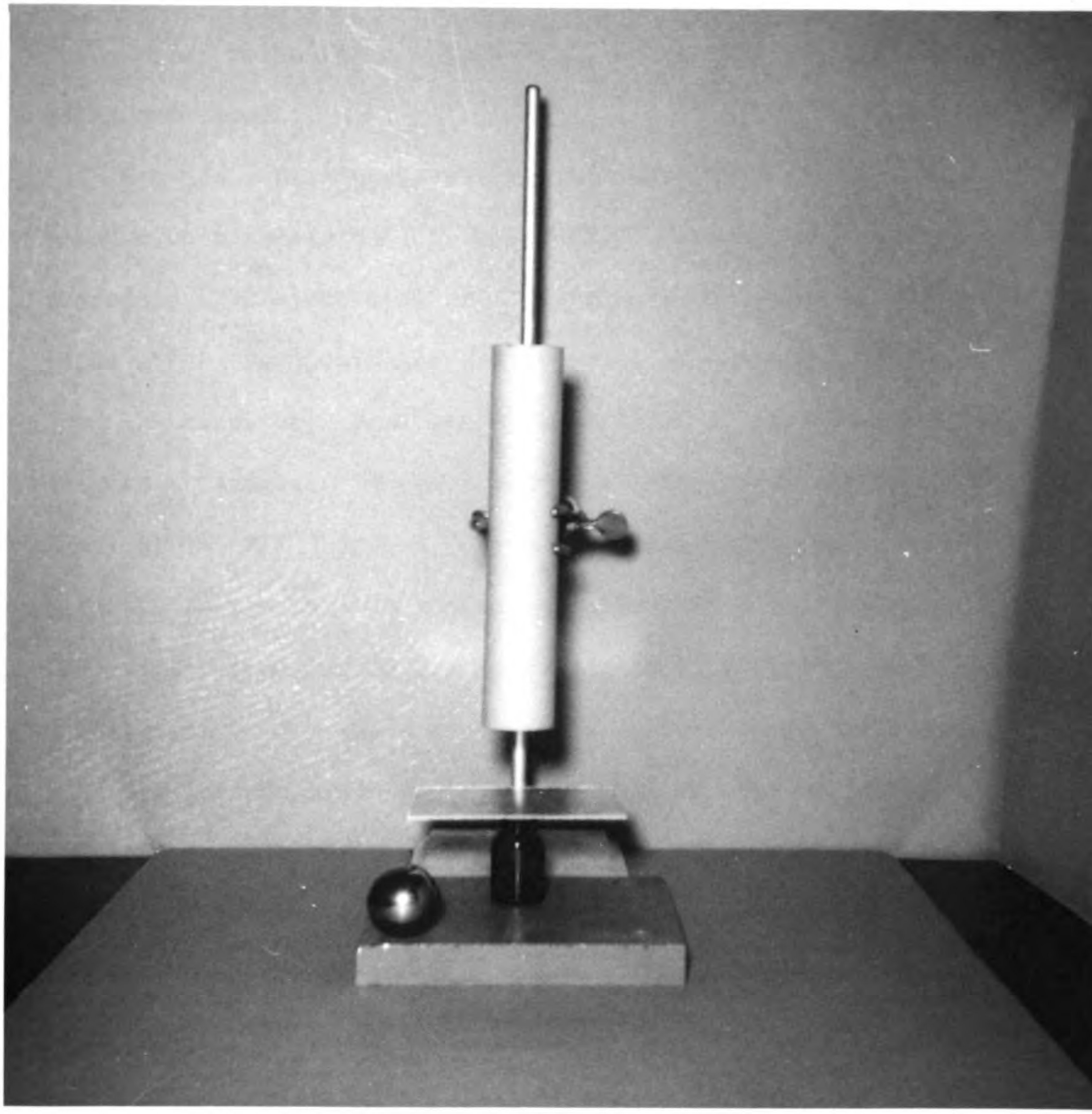

FIGURE 4

Impact apparatus ready for testing

fell on a steel plate 3/32 of an inch thick so as to distribute the impact over the entire cap rather than just at the point of impact. The samples rested on a 1 inch thick steel base plate while undergoing the impact.

Because preliminary testing indicated that the phenolic caps cracked when receiving 2 foot-pounds of impact, only metal caps were tested in the impact studies. These were subjected to both 1 foot-pound and 2 foot-pound impacts, but not on the same container.

The steel ball used had a diameter of 1 13/16 inches, and weighed 14 ounces. It was dropped, by hand, from a height of 1 1/7 feet, or 13 23/32 inches, above the steel plate which rested directly on the cap, to impart approximately a 1 foot-pound impact. The 2 foot-pound impact was approximated by dropping the ball from a height of 2 2/7 feet, or 27 7/16 inches, above the plate.

The procedure was identical to that of top loading in that bottles were filled in groups of ten, the caps were applied with the proper torque, and then after all were capped they were subjected to impact and opened in order. Again twenty samples were run for each cap.

All cap applications, release torque testing, top loading, and impacting were done under ambient conditions, the same as those of Condition 2.

ANALYSIS OF DATA

In addition to the individual test results, the following tables present the group's range (r), average release torque ($\bar{x}$), standard deviation (s), and its average release torque expressed as a decimal fraction of application torque (R). For example, a figure of .25A would indicate that the average release torque of the group equaled 25 percent of the application torque.

The standard deviation as used in this thesis, is merely to give an indication of the width or spread of a group's release torque values and thereby give an idea of their consistency. The higher the standard deviation value, the lower the consistency of results of that particular group.

The standard deviation was calculated by the formula:

$$s = \sqrt{\frac{N\sum x^2 - (\sum x)^2}{N\ (N-1)}}$$

In this formula, "s" stands for standard deviation, "x" stands for release torque, and "N" stands for the number of samples in the group. See reference (8).

The "R factor" is found by merely dividing the average release torque for a group by the application torque with which the caps were put onto the members of the group.

The following pages contain the tables of the experimental data gathered, and comments which summarize the data. In the comments, only the cap size and material are referred to because all liners in the experiment are the same, and the caps determined the bottle and application torque used (see EXPERIMENTAL PROCEDURE).

While reviewing the following tables and commentary, it should be remembered that in addition to experimental error, both in performing tests and in reading the Torque Tester gauge, material variations may cause differences between individual sample results. For instance, a good seal depends on the cap liner being held firmly against the sealing surface of the bottle, and the holding firmness depends on the application torque. The application torque, in turn, is determined by the friction developed between the cap and bottle threads. Poor glass surface or bottles from worn molds may increase the friction and absorb an undue proportion of the application torque, thereby weakening the seal and affecting the release torque (9). In addition to the items mentioned in this example, the factors listed in the BACKGROUND section above play a part in determining the amount of release torque retained. The June, 1962 edition of Modern Packaging contains an article exploring the probabilities of looseness of fit for bottles and caps (10).

TABLE 1

RELEASE TORQUE RESULTS, CONDITION 1 (40°F., AMBIENT HUMIDITY),

SIZE 20-405 BOTTLES, APPLICATION TORQUE - 10 INCH-POUNDS.

METAL CAPS		PHENOLIC CAPS	
5 DAY STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
1. 4.0 in-lbs.	1. 1.5 in-lbs.	1. 5.5 in-lbs.	1. 6.5 in-lbs.
2. 4.0	2. 2.0	2. 6.0	2. 8.0
3. 3.5	3. 2.0	3. 5.5	3. 7.5
4. 4.0	4. 1.5	4. 7.0	4. 7.0
5. 3.5	5. 1.5	5. 5.5	5. 7.0
6. 3.0	6. 3.5	6. 6.0	6. 6.0
7. 4.0	7. 1.0	7. 5.0	7. 7.0
8. 3.5	8. 1.5	8. 5.5	8. 7.0
9. 5.0	9. 1.0	9. 6.0	9. 6.0
10. 3.5	10. 3.0	10. 6.5	10. 6.5
r 3.0-5.0=2.0	r 1.0-3.5=2.5	r 5.0-7.0=2.0	r 6.0-8.0=2.0
$\bar{x}$ 3.8 in-lbs.	$\bar{x}$ 1.9 in-lbs.	$\bar{x}$ 5.9 in-lbs.	$\bar{x}$ 6.9 in-lbs.
s .54	s .82	s .58	s .63
R .38A	R .19A	R .59A	R .69A

Table 1 shows that for 20 millimeter caps, a 10 day storage period for metal caps decreases the "R factor" (release torque expressed as decimal fraction of application torque) to half of the R factor resulting from a 5 day storage period at the same conditions (40°F., ambient humidity). Phenolic caps, meanwhile, actually had an increase of release torque in the 10 day storage as compared to the 5 day storage - .59A after 5 days and .69A after 10 days.

Comparison of metal and phenolic caps stored for 5 days shows that phenolic caps retained nearly six-tenths of the torque they were applied with, while the metal caps retained slightly less than four-tenths. For a 10 day period, the phenolic caps had an R factor over three times that of the metal caps.

The standard deviations of the groups in Table 1 indicate that the data found is quite consistent.

TABLE 2

RELEASE TORQUE RESULTS, CONDITION 1 (40°F., AMBIENT HUMIDITY), SIZE 28-405 BOTTLES, APPLICATION TORQUE - 15 INCH-POUNDS.

METAL CAPS		PHENOLIC CAPS	
5 DAY STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
inch-pounds	inch-pounds	inch-pounds	inch-pounds
1. 8.0	1. 6.0	1. 11.0	1. 13.0
2. 5.5	2. 6.5	2. 11.0	2. 13.0
3. 4.0	3. 6.5	3. 12.0	3. 14.5
4. 8.5	4. 6.0	4. 12.5	4. 13.0
5. 6.0	5. 7.0	5. 12.0	5. 14.0
6. 7.0	6. 5.0	6. 10.0	6. 13.0
7. 5.5	7. 7.0	7. 10.0	7. 13.5
8. 7.0	8. 6.5	8. 10.5	8. 12.5
9. 8.0	9. 6.0	9. 10.5	9. 12.0
10. 7.5	10. 7.0	10. 11.0	10. 13.0
r 4.0-8.5= 4.5	r 5.0-7.0= 2.0	r 10.0-12.5=2.5	r 12.0-14.5= 2.5
$\bar{x}$ 6.7 in-lbs.	$\bar{x}$ 6.4 in-lbs.	$\bar{x}$ 11.1 in-lbs.	$\bar{x}$ 13.2 in-lbs.
s 1.42	s .63	s .86	s .71
R .45A	R .43A	R .74A	R .88A

Except for the 10 day storage of metal caps, the data in Table 2, which concerns 28 millimeter caps at Condition 1, is not as consistent as that in Table 1 according to their standard deviations. However, eliminating the most devious reading, 4.0 (item 3-5 day storage, metal caps), raises the release torque average only 0.3 inch-pounds to 7.0 inch-pounds. And while the standard deviation is lowered 0.30 to 1.12, the R factor is only increased 0.02 to .47A. Because the R factor changes so slightly, the Table 2 28 millimeter caps are compared in the same manner as the Table 1 caps, but using the corrected value, i.e. without using the 4.0 reading noted above.

Unlike the 20 millimeter caps with their great loss of release torque between the 5 and 10 day periods, the 28 millimeter caps had an R factor only .04A less for the 10 day storage than for the 5 day storage. The phenolic caps again increased their torque retention at the longer storage period, this time by 0.14A as compared to the 20 millimeter caps' 0.10A.

Also as in Table 1, the phenolic caps retained more torque than the metal caps. For 5 day storage they held .27A more than the metal caps, and for 10 day storage they retained over twice as much.

Comparing Table 1 and Table 2 shows that the larger caps retained torque more effectively than the smaller ones. The 28 millimeter metal caps at 5 and 10 day storage periods had R factors of .09A and .24A more, respectively, than their 20 millimeter counterparts. The 28 millimeter phenolics had .15A and .19A more at 5 and 10 day periods, respectively, than the 20 millimeter phenolics.

TABLE 3

RELEASE TORQUE RESULTS, CONDITION 2 (ROOM TEMPERATURE, AMBIENT HUMIDITY), SIZE 20-405 BOTTLES, APPLICATION TORQUE - 10 INCH-POUNDS.

METAL CAPS		PHENOLIC CAPS	
5 DAY STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
1. 4.0 in-lbs.	1. 2.5 in-lbs.	1. 6.0 in-lbs.	1. 5.5 in-lbs.
2. 3.5	2. 3.5	2. 6.0	2. 6.5
3. 5.5	3. 1.5	3. 6.0	3. 6.0
4. 4.5	4. 2.5	4. 6.0	4. 5.5
5. 3.0	5. 4.5	5. 5.5	5. 5.5
6. 4.5	6. 3.5	6. 5.5	6. 5.0
7. 3.0	7. 5.5	7. 6.0	7. 5.5
8. 3.5	8. 3.0	8. 6.5	8. 6.0
9. 4.5	9. 3.0	9. 5.5	9. 6.0
10. 4.0	10. 1.0	10. 6.0	10. 6.0
r 3.0-5.5=2.5	r 1.0-5.5=4.5	r 5.5-6.5=1.0	r 5.0-6.0 =1.0
$\bar{x}$ 4.0 in-lbs.	$\bar{x}$ 3.1 in-lbs.	$\bar{x}$ 5.9 in-lbs.	$\bar{x}$ 5.8 in-lbs.
s .78	s 1.32	s .32	s .43
R .40A	R .31A	R .59A	R .58A

At room temperature and humidity (Condition 2, Table 3), the 20 millimeter phenolic caps retain their application torque practically equally well for 5 and 10 day storage periods. For the metal caps, the 10 day group has quite a high standard deviation. Eliminating the 4.5 and 5.5 readings, which seem to be out of line, leaves a range of 1.0-3.5, an average of 2.6 inch-pounds, a standard deviation of 0.90, and an R factor of .26A. Using the refined information, the metal caps lose .14A between the fifth and tenth day of storage.

Also using the refined R factor, a comparison of the caps stored for 10 days shows the phenolics retaining twice as much torque as the metal caps. After 5 days of storage, phenolic caps kept .19A more torque than the metal caps did.

Comparing the metal caps in Table 3 (Condition 2) and those in Table 1 (Condition 1) shows that they both had less release torque after 10 days than after 5 days. The 20 millimeter phenolic caps in those tables had identical R factors for 5 day storage periods, but the Condition 1 phenolic caps at 10 day storage had .09A more release torque than those under Condition 2 for 10 days.

TABLE 4

RELEASE TORQUE RESULTS, CONDITION 2 (ROOM TEMPERATURE, AMBIENT HUMIDITY), SIZE 28-405 BOTTLES, APPLICATION TORQUE - 15 INCH-POUNDS.

METAL CAPS		PHENOLIC CAPS	
5 DAY STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
inch-pounds	inch-pounds	inch-pounds	inch-pounds
1. 5.0	1. 8.5	1. 10.5	1. 9.0
2. 6.5	2. 7.5	2. 11.0	2. 10.0
3. 9.5	3. 6.5	3. 11.0	3. 10.0
4. 6.0	4. 7.5	4. 11.5	4. 8.5
5. 8.0	5. 6.5	5. 10.5	5. 10.0
6. 8.0	6. 8.5	6. 11.0	6. 10.5
7. 8.0	7. 7.5	7. 10.5	7. 10.0
8. 7.0	8. 8.0	8. 11.0	8. 10.0
9. 7.5	9. 7.5	9. 9.5	9. 11.0
10. 9.5	10. 7.0	10. 10.5	10. 11.5
r 5.0-9.5= 4.5	r 6.5-8.5= 2.0	r 9.5-11.5= 2.0	r 8.5-11.5= 3.0
$\bar{x}$ 7.5 in-lbs.	$\bar{x}$ 7.5 in-lbs.	$\bar{x}$ 10.7 in-lbs.	$\bar{x}$ 10.1 in-lbs.
s 1.43	s .71	s .54	s .86
R .50A	R .50A	R .71A	R .67A

In Table 4 (Condition 2, 28 millimeter caps), the metal caps under 5 day storage had a rather high standard deviation. Even so, removing the low reading of 5.0 inch-pounds (because there are no readings closer than 1.0 to it) only reduces the standard deviation to 1.20 and raises the R factor to .52A from .50A. This still leaves the metal caps at 5 day storage and those at 10 day storage practically equal. This is also true of the phenolic caps.

At both 5 and 10 day storage, phenolic caps retain more torque than metal ones: .19A for 5 days and .17A for 10 days.

Under Condition 2, the 28 millimeter caps retain torque more effectively than 20 millimeter caps at all combinations of storage periods and cap materials.

Comparing the 28 millimeter caps under Condition 1 (Table 2) with those under Condition 2 (Table 4) shows that the metal caps under Condition 2 kept .05A more torque than those under Condition 1 for 5 day storage (using the corrected values of .47A and .52A), and .07A more for a 10 day period. The phenolic caps are practically equal for 5 day storage, the Condition 1 caps being .03A higher. The Condition 1 caps are even higher for 10 day storage - .21A in this case.

TABLE 5

RELEASE TORQUE RESULTS, CONDITION 3 (100°F., 90-95% RELATIVE HUMIDITY), SIZE 20-405 BOTTLES, APPLICATION TORQUE - 10 INCH-POUNDS.

METAL CAPS		PHENOLIC CAPS	
5 DAY STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
inch-pounds	inch-pounds	inch-pounds	inch-pounds
1. 4.0	1. 3.5	1. 3.0	1. 2.5
2. 3.5	2. 4.0	2. 2.5	2. 2.0
3. 4.0	3. 4.0	3. 2.5	3. 2.5
4. 4.0	4. 3.5	4. 2.5	4. 2.0
5. 4.5	5. 4.0	5. 0.0*	5. 2.0
6. 3.5	6. 4.5	6. 2.0	6. 2.0
7. 3.5	7. 4.0	7. 2.5	7. 2.5
8. 3.0	8. 4.5	8. 2.5	8. 3.0
9. 3.5	9. 4.0	9. 2.5	9. 2.0
10. 4.0	10. 4.0	10. 2.5	10. 2.5
r 3.0-4.5= 1.5	r 3.5-4.5= 1.0	r 2.0-3.0= 1.0	r 2.0-3.0= 1.0
$\bar{x}$ 3.8 in-lbs.	$\bar{x}$ 4.0 in-lbs.	$\bar{x}$ 2.5 in-lbs.	$\bar{x}$ 2.3 in-lbs.
s .43	s .33	s .25	s .35
R .38A	R .40A	R .25A	R .23A

*Inspection of this cap after removal proved it to have a faulty liner, so it was not included in the range, average, etc.

Table 5 shows the effects of extreme storage conditions (100°F., 90-95% relative humidity) on 20 millimeter caps. The metal caps kept practically the same amount of torque - the 5 day samples retaining .38A, and the 10 day, .40A. The phenolic caps were also practically equal - .25A for the 5 day samples compared to .23A for the 10 day sample.

Comparing the 5 day storage figures for metal and phenolic caps shows that the metal caps retained more torque (.38) than the phenolic caps (.25A). They also held more torque after 10 days in conditioning (.40A) than the phenolic caps held (.23A).

The metal caps stored for 5 days under Conditions 2 and 3 vary in torque retention by only .02A, the caps under Condition 2 being the larger at .40A. The 10 day period caused a much larger differential, for using the corrected value the Condition 2 caps have an R factor of .26A, while the Condition 3 caps have one of .40A.

The phenolic caps, meanwhile, show an opposite trend. They have higher retention factors for Condition 2 storage. The 5 day Condition 2 factor is .59A, while Condition 3's factor is .25A. Ten day storage causes essentially the same situation, the spread being .58A to .23A.

TABLE 6

RELEASE TORQUE RESULTS, CONDITION 3 (100°F., 90-95% RELATIVE HUMIDITY), SIZE 28-405 BOTTLES, APPLICATION TORQUE - 15 INCH-POUNDS.

* METAL CAPS		PHENOLIC CAPS	
5 Day STORAGE	10 DAY STORAGE	5 DAY STORAGE	10 DAY STORAGE
1. 7.5 in-lbs.	1. 8.0 in-lbs.	1. 3.5 in-lbs.	1. 2.5 in-lbs.
2. 8.0*	2. 8.0	2. 4.0	2. 3.0
3. 7.5	3. 7.5	3. 3.5	3. 4.0
4. 8.0	4. 8.5	4. 3.5	4. 2.5
5. 8.0	5. 9.0	5. 4.0	5. 3.0
6. 8.5	6. 8.0*	6. 4.0	6. 0.5
7. 5.0*	7. 10.5	7. 4.0	7. 0.5
8. 8.0	8. 9.5	8. 3.5	8. 4.0
9. 8.0	9. 8.5	9. 4.0	9. 3.0
10. 8.0	10. 8.5	10. 3.5	10. 3.5
r 5.0-8.5= 3.5	r 7.5-10.5= 3.0	r 3.5-4.0= 0.5	r 0.5-4.0= 3.5
$\bar{x}$ 7.7 in-lbs.	$\bar{x}$ 8.6 in-lbs.	$\bar{x}$ 3.8 in-lbs.	$\bar{x}$ 2.7 in-lbs.
s .97	s .88	s .26	s 1.25
R .51A	R .57A	R .25A	R .18A

* These caps had rust on their threads when removed from the humidity cabinet.

Table 6 shows that two groups of caps had fairly high standard deviations. However, eliminating the 5.0 reading which was given by a cap that was rusty upon removal from the metal cap 5 day storage group, reduces its standard deviation to 0.09 and raises its R factor 0.02 to .53A. In the phenolic cap 10 day storage results, the two 0.5 readings seem abnormally low. Eliminating them gives a standard deviation of 0.59 and the R factor increases from .18A to .21A. The revised R factors will be used in the following comparisons.

The metal caps differ in torque retention by only .04A for the 5 and 10 day storage periods. The caps differ by .04A also, with the 5 day caps, at .25A, the larger.

The metal caps are a little over twice as effective as the phenolic caps in retaining torque over the 5 day period, and over 2½ times as effective for the 10 day period.

Comparison of the R factors for the 28 millimeter caps and the 20 millimeter caps after storage under Condition 3 (Tables 5 and 6) shows that the phenolic caps are equal after 5 day storage and differ by only .02A after 10 days. The metal caps, though, show better torque retention by the 28 millimeter size than by the 20 millimeter size. The differences being .15A for 5 day storage and .17A for 10 day storage.

Although 28 millimeter metal caps stored for 5 days under Condition 2 (Table 4) and Condition 3 (Table 6) have practically identical R factors, .52A and .53A, respectively; 28 millimeter phenolic caps show a wide variation, the Condition 2 caps having a retention factor nearly three times that of the Condition 3 caps.

For 10 day storage, the metal caps under Condition 3 had an R factor of .57A and those under Condition 2 had one of .50A. As in the 5 day results, the phenolic caps stored for 10 days had a wide variation of release values, this time the Condition 2 value being over three times as great as the Condition 3 value.

Metal caps, 28 millimeter, which underwent Condition 3 had higher torque retention than those undergoing Condition 1 (Table 2). They were .06A greater for the 5 day period, and .14A greater after 10 days.

The phenolic caps again show a great spread, Condition 1 caps being almost three times as effective in retaining torque as Condition 3 caps for a 5 day storage period, and over four times more effective for a 10 day period.

TABLE 7

RELEASE TORQUE RESULTS, IMMEDIATE REMOVAL UNDER AMBIENT CONDITIONS

METAL CAPS		PHENOLIC CAPS	
20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.	20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.
1. 5.5 in-lbs	1. 7.0 in-lbs.	1. 5.0 in-lbs.	1. 7.0 in-lbs.
2. 5.0	2. 8.0	2. 5.0	2. 8.0
3. 4.0	3. 9.0	3. 5.0	3. 7.0
4. 5.0	4. 9.0	4. 5.0	4. 7.0
5. 4.0	5. 8.5	5. 4.5	5. 7.5
6. 5.0	6. 7.5	6. 5.0	6. 7.0
7. 5.0	7. 8.0	7. 4.5	7. 7.0
8. 6.0	8. 9.0	8. 4.0	8. 7.0
9. 5.0	9. 8.0	9. 4.5	9. 7.5
10. 5.5	10. 7.0	10. 5.0	10. 7.0
r 4.0-6.0= 2.0	r 7.0-9.0= 2.0	r 4.0-5.0= 1.0	r 7.0-8.0= 1.0
$\bar{x}$ 5.0 in-lbs.	$\bar{x}$ 8.1 in-lbs.	$\bar{x}$ 4.8 in-lbs.	$\bar{x}$ 7.2 in-lbs.
s .62	s .78	s .35	s .35
R .50A	R .54A	R .48A	R .48A

Table 7 shows that all caps tested lost approximately half of the torque they had been put on with, almost as soon as they were on. The 20 millimeter metal caps lost exactly half, having an R factor of .50A. The 28 millimeter caps held a little more torque as they had an R factor of .54A. Both sizes of phenolic caps had release torques of .48A.

Comparing the 20 millimeter caps shows the metal and phenolics to be almost equal, the metal caps retaining only .02A more than the phenolic caps. The case is much the same for the 28 millimeter caps, with the R factor of the metal caps being .06A greater than that of the phenolic caps.

TABLE 8

COMPARISON OF R FACTORS OF IMMEDIATE RELEASE AND STORAGE RESULTS*

	IMMEDIATE RELEASE	5 DAY STORAGE	10 DAY STORAGE
CONDITION 1			
20 mm. METAL CAPS	.50A	.38A	.19A
20 mm. PHENOLIC CAPS	.48A	.59A	.69A
28 mm. METAL CAPS	.54A	.47A	.43A
28 mm. PHENOLIC CAPS	.48A	.74A	.88A
CONDITION 2			
20 mm. METAL CAPS	.50A	.40A	.26A
20 mm. PHENOLIC CAPS	.48A	.59A	.58A
28 mm. METAL CAPS	.54A	.52A	.50A
28 mm. PHENOLIC CAPS	.48A	.71A	.67A
CONDITION 3			
20 mm. METAL CAPS	.50A	.38A	.40A
20 mm. PHENOLIC CAPS	.48A	.25A	.23A
28 mm. METAL CAPS	.54A	.53A	.57A
28 mm. PHENOLIC CAPS	.48A	.25A	.21A

* Corrected R factors are used where applicable.

Through the comparison of the Condition 1 results with the immediate release torque results (Table 8), it is discovered that 20 millimeter metal caps decline in release torque from .50A for immediate release to .38A after 5 days storage at 40°F. to .19A after 10 days storage at 40°F. The 20 millimeter phenolic caps, however, go in the opposite direction - from .48A for immediate release to .59A after 5 days and .69A after 10 days. The same trends are apparent for 28 millimeter caps, not to as great a degree in the metal caps, but to a greater degree in the phenolics. The metal caps drop from .54A to .47A (corrected value) to .43A and the phenolic caps rise from .48A to .74A to .88A for immediate release, 5 day, and 10 day storage, respectively. This order of presentation will be used for the rest of the comparisons in this section.

A comparison of immediate release results and the results of caps stored under Condition 2 (approximately 70°F.) reveals that the 20 millimeter metal caps again follow the decreasing trend. Their R factor drops from .50A to .40A to .26A (corrected value). As in Condition 1, the 20 millimeter phenolic caps initially rise, from .48A to .59A, but then level off to .58A after 10 days of storage. The 28 millimeter phenolics also exhibit this pattern, going from .48A to .71A to .67A. The 28 millimeter metal caps, meanwhile, remain practically equal, going from .50A to .52A (corrected value) back to .50A.

Comparison of Condition 3 (extreme condition) results and immediate release findings gives very different trends. The 20 millimeter metal caps drop from .50A to .38A and level off at .40A. The phenolic caps drop even more, from .48A to .25A, and then level off at .23A. The 28 millimeter metal caps, unlike the 20 millimeter, rise from .50A to .53A (corrected value) to .57A. The 28 millimeter phenolic caps are very similar to their 20 millimeter counterparts, dropping from .48A to .25A and leveling off at .21A (corrected value).

TABLE 9

RELEASE TORQUE RESULTS, 200 POUND TOP LOAD TEST

METAL CAPS		PHENOLIC CAPS	
20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.	20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.
1. 2.5 in-lbs.	1. 4.5 in-lbs.	1. 1.0 in-lbs.	1. 4.5 in-lbs.
2. 2.0	2. 6.0	2. 2.5	2. 4.5
3. 2.0	3. 6.5	3. 1.0	3. 5.0
4. 2.0	4. 6.0	4. 1.5	4. 5.0
5. 3.0	5. 5.5	5. 1.5	5. 5.5
6. 2.5	6. 4.5	6. 2.0	6. 5.0
7. 2.0	7. 5.0	7. 0.0	7. 4.5
8. 1.0	8. 6.5	8. 1.5	8. 6.0
9. 2.0	9. 4.0	9. 2.0	9. 4.0
10. 0.0	10. 3.5	10. 2.5	10. 4.0
11. 2.5	11. 5.0	11. 2.5	11. 4.5
12. 2.0	12. 4.5	12. 1.5	12. 4.5
13. 2.5	13. 5.5	13. 2.0	13. 4.5
14. 1.0	14. 4.5	14. 0.5	14. 4.0
15. 2.5	15. 3.0	15. 2.5	15. 5.0
16. 2.0	16. 4.5	16. 2.0	16. 4.5
17. 2.0	17. 5.0	17. 2.0	17. 6.0
18. 3.0	18. 5.5	18. 2.5	18. 5.0
19. 2.0	19. 5.0	19. 1.0	19. 5.5
20. 2.0	20. 4.5	20. 1.5	20. 6.0
r 0.0-3.0= 3.0	r 3.0-6.5= 3.5	r 0.0-2.5= 2.5	r 4.0-6.0= 2.0
$\bar{x}$ 2.0 in-lbs.	$\bar{x}$ 5.0 in-lbs.	$\bar{x}$ 1.7 in-lbs.	$\bar{x}$ 4.9 in-lbs.
s .70	s .92	s .71	s .65
R .20A	R .33A	R .17A	R .33A

In Table 9 we see that the metal (20 millimeter metal) caps retained slightly more torque after undergoing the 200 pound top load than the 20 millimeter phenolic caps did, .20A to .17A. The metal and phenolic 28 millimeter caps retained the same fraction - .33A.

For both metal and phenolic caps, the 28 millimeter size retained more torque than the 20 millimeter size - .13A in the case of metal, and nearly twice as much (.33A to .17A) in phenolic's case.

Comparing top loading results (Table 9) to immediate release results (Table 7) reveals that top loaded samples have lower R factors in all cases - 20 millimeter, top loaded metal caps have release torques $2\frac{1}{2}$ times smaller (.50A to .20A), and phenolic caps have them almost three times smaller (.48A to .17A).

TABLE 10

COMPARISON OF R FACTORS OF TOP LOAD AND STORAGE RESULTS*

	TOP LOADED	5 DAY STORAGE	10 DAY STORAGE
CONDITION 1			
20 mm. METAL CAPS	.20A	.38A	.19A
20 mm. PHENOLIC CAPS	.17A	.59A	.69A
28 mm. METAL CAPS	.33A	.47A	.43A
28 mm. PHENOLIC CAPS	.33A	.74A	.88A
CONDITION 2			
20 mm. METAL CAPS	.20A	.40A	.26A
20 mm. PHENOLIC CAPS	.17A	.59A	.58A
28 mm. METAL CAPS	.33A	.52A	.50A
28 mm. PHENOLIC CAPS	.33A	.71A	.67A
CONDITION 3			
20 mm. METAL CAPS	.20A	.38A	.40A
20 mm. PHENOLIC CAPS	.17A	.25A	.23A
28 mm. METAL CAPS	.33A	.53A	.57A
28 mm. PHENOLIC CAPS	.33A	.25A	.21A

* Corrected R factors are used where applicable.

In Table 10 it can be seen that top loading reduces torque to a greater degree than storage at 40°F. for all time - material - size combinations except the 10 day - metal - 20 millimeter caps, which have nearly the same R factor for both. For the 28 millimeter metal caps, the Condition 1 caps are at least .10A higher than the top loaded caps, for each storage period. The 20 millimeter phenolic caps, meanwhile, have R factors approximately 3½ and 4 times higher for 5 and 10 day storage periods, respectively, than for top loading. The 5 day figure for 28 millimeter phenolic caps is .41A higher than that for top loading, while the 10 day figure is .55A higher.

Under Condition 2 the 20 millimeter metal caps under 5 day storage double the R factor of those undergoing top loading, but fall back to only .06A more after 10 days of storage. As in Condition 1, the 20 millimeter phenolic caps from 5 day storage more than triple the top loaded ones; but in this case, they then level off. The same is true for 28 millimeter phenolic caps; they more than double the top loaded caps, and then level off. The 28 millimeter metal caps increase by .19A between top loaded samples and Condition 2, 5 day samples, and then level off.

Using the order of top loading to 5 day to 10 day storage values, we see that under Condition 3 both 20 and 28 millimeter caps increase by about .20A and then level off. The 20 millimeter phenolic caps increase by .08A and level off, but the 28 millimeter caps decrease steadily.

TABLE 11

RELEASE TORQUE RESULTS, IMPACT TESTS ON METAL CAPS

1 FOOT-POUND IMPACT TEST		2 FOOT-POUND IMPACT TEST	
20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.	20-405 SIZE APP. TORQUE 10 in-lbs.	28-405 SIZE APP. TORQUE 15 in-lbs.
1. 2.5 in-lbs.	1. 5.0 in-lbs.	1. 1.5 in-lbs.	1. 1.5 in-lbs.
2. 2.5	2. 4.0	2. 0.5	2. 5.5
3. 1.5	3. 3.5	3. 2.5	3. 3.5
4. 2.0	4. 4.0	4. 1.0	4. 2.5
5. 2.0	5. 3.5	5. 1.5	5. 5.0
6. 2.0	6. 6.0	6. 0.5	6. 2.5
7. 2.5	7. 5.0	7. 1.0	7. 3.5
8. 2.0	8. 5.0	8. 1.5	8. 3.0
9. 2.0	9. 5.0	9. 1.0	9. 3.5
10. 1.5	10. 6.0	10. 1.0	10. 2.5
11. 2.5	11. 3.5	11. 4.0	11. 2.5
12. 2.5	12. 5.0	12. 2.0	12. 4.5
13. 2.0	13. 4.0	13. 3.0	13. 3.5
14. 2.0	14. 3.5	14. 2.0	14. 3.5
15. 2.5	15. 5.5	15. 2.5	15. 3.5
16. 3.0	16. 4.5	16. 2.0	16. 3.0
17. 1.5	17. 6.5	17. 3.0	17. 3.0
18. 2.5	18. 4.0	18. 1.0	18. 3.0
19. 2.0	19. 6.0	19. 2.5	19. 4.0
20. 1.5	20. 5.5	20. 1.5	20. 2.0
r 1.5-3.0= 1.5	r 3.5-6.5= 3.0	r 0.5-4.0= 3.5	r 1.5-5.5= 4.0
$\bar{x}$ 2.1 in-lbs.	$\bar{x}$ 4.8 in-lbs.	$\bar{x}$ 1.8 in-lbs.	$\bar{x}$ 3.3 in-lbs.
s .14	s .97	s .93	s .97
R .21A	R .32A	R .18A	R .22A

Table 11 shows that the 28 millimeter caps retained more torque than the 20 millimeter caps after both 1 and 2 foot-pounds of impact. The differnce was only .04A at the higher impact level, but was .11A at the 1 foot-pound level. Both sizes of caps had lower torque retention after 2 foot-pounds of impact than after 1 foot-pound. The 20 millimeter caps had .03A less, and the 28's had .10A less.

In comparison to immediate release torque, the 20 millimeter metal caps after a 1 foot-pound impact had almost 2½ times less torque retention. In the case of the 28 millimeter caps, .22A more release torque was lost by the impact samples than by the immediate release torque samples.

Comparing the 2 foot-pound impact results with the immediate release samples shows the same results, but to a greater degree. The 20 millimeter caps that were subjected to impact gave release torques approximately 2½ times less than immediate release samples, as did the 28 millimeter caps.

The 1 foot-pound impact-tested samples (Table 11) have almost the same R factors as the metal, 200 pound top loaded caps (Table 9). This is also true for the 20 millimeter caps which underwent either a 200 pound top load or a 2 foot-pound impact. They varied by .02A, while the others varied by only .01A. The situation changes for 28 millimeter, 2 foot-pound impact tested caps though; they retain .11A less torque than their 200 pound top loaded counterparts.

TABLE 12

COMPARISONS OF R FACTORS OF IMPACT AND STORAGE RESULTS*

A.	1 FT-LB IMPACT	5 DAY STORAGE	10 DAY STORAGE
CONDITION 1			
20 mm. METAL CAPS	.21A	.38A	.19A
28 mm. METAL CAPS	.32A	.47A	.43A
CONDITION 2			
20 mm. METAL CAPS	.21A	.40A	.26A
28 mm. METAL CAPS	.32A	.52A	.50A
CONDITION 3			
20 mm. METAL CAPS	.21A	.38A	.40A
28 mm. METAL CAPS	.32A	.53A	.57A

B.	2 FT-LB IMPACT	5 DAY STORAGE	10 DAY STORAGE
CONDITION 1			
20 mm. METAL CAPS	.18A	.38A	.19A
28 mm. METAL CAPS	.22A	.47A	.43A
CONDITION 2			
20 mm. METAL CAPS	.18A	.40A	.26A
28 mm. METAL CAPS	.22A	.52A	.50A
CONDITION 3			
20 mm. METAL CAPS	.18A	.38A	.40A
28 mm. METAL CAPS	.22A	.53A	.57A

* Corrected values used where applicable.

Table 12 shows that the 1 foot-pound impact results compare with the storage condition results much the same as the 200 pound top load results did. Again, only the 20 millimeter caps stored under Condition 1 for 10 days had a lower R factor than the caps which underwent the impact test. In fact, only it and the 20 millimeter, Condition 2 caps have 10 day storage R factors considerably less than their 5 day factors. All the others, after rising considerably between the 1 foot-pound and 5 day results, level off in their 10 day storage R factor.

Except for the fact that the Condition 1, 10 day stored, 20 millimeter caps' R factor does not fall quite below their 2 foot-pound impact results, the same is true of the 2 foot-pound results as is for the 1 foot-pound results. The differences between the 5 day and 2 foot-pound R factors are a little greater, though, especially for 28 millimeter caps.

CONCLUSIONS

An important conclusion which may be reached from the data in the preceding section, is that small caps constructed of tin plated steel or black phenolic plastic and having pulp/vinylite liners lose approximately half of their application torque within the first five minutes of being capped.

If the caps are not removed immediately, but the caps and bottles are allowed to remain at room conditions for a period of time, the release torque of metal caps declines steadily, with the smaller caps dropping at a much higher rate. The release torque of phenolic caps, meanwhile, increases for a few days, and then begins to decline. The larger caps show these changes to a greater degree than the smaller caps.

Storage at 40°F. causes the release torque of metal caps to decrease just as those stored at room conditions, except that the larger caps decrease a little faster in the cooler condition. The refrigeration causes phenolic caps to have a steadily rising release torque for at least 10 days, with the larger caps again having larger increments.

The release torque of metal caps stored at extreme conditions (100°F. and 90-95% relative humidity) declined for a few days, and then began to rise. The larger metal caps are more stable than the smaller ones. Extreme conditions cause phenolic caps, regardless of size, to lose torque rapidly for a few days, and then to seemingly level off.

In general then, it may be said that storage at any condition causes metal caps to lose release torque; and that storage at any temperature between 40°F. and 70°F. causes phenolic caps to improve on what their immediate release torque would be, while storage at high temperature and humidity causes phenolic caps to lose torque.

It must be remembered that the conclusions above are derived from the results of tests on only two sizes of caps, both relatively small, with only one kind of liner. Also, no intermediate tests (between the immediate and 5 day or between the 5 day and 10 day tests) were run; nor were any tests of longer than 10 day storage run. And it is possible that testing other size caps, or different kinds of liners, or more storage periods would alter or completely change the above trends.

Top loading decreases the torque retained by caps considerably, the amount depending more on the cap size than on the material. In general, it also decreases torque retention by greater amounts than storage at various conditions does. The exceptions being the smaller metal caps at normal or refrigerated conditions for 10 days or longer, and the larger phenolic caps stored at high temperature and humidity.

The conclusions about the effects of top loading are subject to the same limitations as the conditioning results above, plus the fact that more top loading weights (both greater and less than 200 pounds) would need to be tested for more inclusive, and still reliable, results.

Impact to the top of metal caps also causes them to lose more of their release torque than storage causes them to lose. The 20 millimeter caps stored for 10 days at 40°F., as compared to those subjected to 1 foot-pound of impact, are an exception to this statement.

The data also indicates that the greater the impact, the greater the amount of torque lost. This effect seems to be greater on the larger caps than on the smaller caps.

Again, the reliability of these conclusions are limited by the small number of trials, cap sizes, etc. tested. Increasing the number of all variables mentioned above, and adding more impact levels to the experiment, would lend more conclusiveness to the results.

SUGGESTIONS FOR FURTHER STUDY

Expanding the tests used in this experiment to remove the limitations mentioned in the CONCLUSIONS section would be advisable.

Testing many sizes of caps - made of the various materials available and utilizing more than just one kind of liner - at both shorter and longer intervals of storage in a wider range of conditions would give a much more complete and comprehensive picture of the effects of conditioning on release torque, than this study, limited by both time and availability of materials, was able to present. It would also be beneficial to test a wide range of application torques.

Another area that might provide valuable results is a study on the effects of the contents of a bottle on release torque, taking the above cap and conditioning variables into account.

Just as in the conditioning tests, it would be wise to increase the cap variations in the physical tests, at the same time adding more top loads and impact levels to the procedure. Both reduced and increased loads and impacts would be advisable.

Other physical tests - such as shipping, vibration, incline-impact, and drop tests - would also undoubtedly have effects on release torque, and studies of these are recommendable.

All of the above tests could also be performed using lug caps or rolled-on caps, in addition to screw caps.

LIST OF REFERENCES

1. Eli Lilly and Company, Indianapolis, Indiana. Telephone interview with R.J. Schnorr, Package Design Chief, February, 1964.

2. Glass Container Manufacturers Institute, East Lansing, Michigan. Personal interview with Dr. J.G. Turk, March, 1964.

3. Owens-Illinois Glass Company, Toledo, Ohio. Personal interview with G.V. Mumford and R.K. Flaskamp, Closure Division, March, 1964.

4. Muraski, T.C., "How Much Torque Is Just Right," Package Engineering, Vol. 7, No. 8 (August, 1962), p. 46.

5. Sheffler, R.J., "Evaluating Performance of the Screw Cap for Glass Containers," Glass Packer, Vol. 40, No. 8 (August, 1961), p. 32.

6. Curtis, E.A., "Simple Methods and Good Judgment Help You Predict Package Shelf Life," Package Engineering, Vol. 7, No. 5 (May, 1961), p.45.

7. The Owens-Illinois Torque Tester Manual , Owens-Illinois Glass Company, Toledo, Ohio.

8. Weinberg, G.H., and Schumaker, J.A., Statistics: An Intuitive Approach, (Belmont, California: Wadsworth Publishing Company, Inc.), 1962.

9. Hughs, D.A., "Demands on the Bottle Today," Glass Technology, Vol. 2, No. 3 (June, 1961), p. 101.

10. Sheffler, R.J., "Screw Cap Problems," Modern Packaging, Vol. 35, No. 10 (June, 1962), p. 150.