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The Effect of Induction Sealing and Time on Removal Torque of Continuous-Thread and Child Resistant Plastic Closures

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THE EFFECT OF INDUCTION SEALING AND TIME ON REMOVAL TORQUE OF CONTINUOUS-THREAD AND CHILD RESISTANT PLASTIC CLOSURES

by

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CERTIFICATE OF APPROVAL
M.S. DEGREE THESIS

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ABSTRACT

EFFECT OF INDUCTION SEALING AND TIME ON REMOVAL TORQUE OF CONTINUOUS-THREAD AND CHILD RESISTANT PLASTIC CLOSURES

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This thesis investigated the effect of an induction sealing process and time on the removal torque of continuous thread and child resistant plastic closures. An application torque of 19 in-lb was applied to the high density polyethylene (HDPE) bottle/closure systems. After passing the bottle/closures through the induction sealer, the immediate removal torque values were measured and recorded. Additionally, sampled bottles/closures were set aside and removal torques were measured over time.

A statistically significant ($P<0.001$) removal torque reduction was observed from the non-induction sealing process versus the induction sealing process, varying from 60.7% to 72.6%. The data confirmed that the removal torque values were affected by the induction sealing process. The data also indicated that the removal torque values increased during the two weeks duration after the induction sealing process. The removal torque values increased from 24.5% to 44.9%.

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1 Introduction, Research Hypotheses and Review of Literature

1.1 Introduction

For a plastic bottle/closure system, torque plays an important role. Torque is the resistance to application or removal of a threaded closure. Application torque is a measure of the tightness to which the capping machine turns the closure. Removal torque is the amount of force necessary to loosen and remove the closure (Soroka 2002). Torque has an impact on child resistance, senior friendliness, and packaging integrity.

Child resistant (CR) closures come in many types. The function of child resistant closure is to prevent undesired access to the product from young children. Example types of CR closures are “press and turn,” where the cap is removed by applying downward force while the closure is rotated; “squeeze and turn,” where the cap is removed by applying force to the side of the closure while the closure is rotated; and “lift and turn,” where the cap is removed by applying upward force while the closure is rotated (Paine 1991). These three CR features are based on the need for two coordinated actions in order to remove the caps. In order for a bottle/closure system to be classified as child resistant (CR), a series of test protocols have to be conducted and passed in accordance to the US Consumer Products Safety Commission, 16 CPR 1700.20 (Soroka 2002). The type of child resistant closure used in the experiments is “push and turn.”

Another part of the bottle/closure requirement is to demonstrate the ease of opening it, or how “senior-friendly” it is. The requirements, similar to CR testing, are also identified in the US Consumer Products Safety Commission, 16 CPR 1700.

Packaging integrity is vital for the pharmaceutical industry. The tamper-evident feature is one that ensures that the products are not tampered with. There are several popular tamper-evident solutions out in the market, such as external tear-off band, external break-off ring, external breakable part, internal tear-off membrane, and internal induction heat seal aluminum foil for plastic bottle/closure system (Giles and Bain 2001). In pharmaceutical bottle packaging applications, the predominant method of providing a tamper-evident seal is to use an induction seal process where a cap with a liner - consisting of a heat seal layer, aluminum foil, and wax paperboard - is applied to the bottle. The bottle/cap system is then passed through an alternating magnetic field induction sealer, which induces an electric current in the aluminum foil, thereby heating up the foil. The plastic facing on the aluminum melts and then adheres to the bottle neck, which results in the tamper-evident seal.

There are two basic type closures that will be used in the study: continuous thread closure and child resistant closure. Continuous thread (CT) closures are designed to screw on and off the container (Selke 1997). It is a single piece closure and requires only a single action to open. Typically, these types of closures are used when the final distribution point in the supply chain are mail order pharmacies or institutional pharmacies, such as hospitals, where the products are repackaged in different containers and are then sent to the patients.

Another type of closure is child resistant (CR). It is a two-piece design. The inner piece is for engaging with the bottle neck. The top of the inner piece has sloped ridges protruding up. The bottom of the outer piece has downward protruding grooves. To close the bottle, the outer cap grooves engage the inner piece grooves as it is turned clockwise. In order to open the cap, a push and turn action is required because the grooves on the inner piece are sloped. If not pushed, the outer cap grooves would glide over the grooves of the inner piece, thus preventing the cap from opening. If the torque is too low, the engagement of the inner piece of the bottle may not be sufficient and the child resistant feature may not be fully engaged, thus the cap can be opened easily without the push and turn actions. In the supply chain, bottles with child resistant closures are usually delivered to the retailer pharmacies, where the product could be dispensed directly to the patient without re-packaging.

1.2 Research Hypotheses

In pharmaceutical bottle packaging applications, the predominant method of providing a tamper-evident seal is using an induction seal. First, it is predicted that samples undergoing an induction sealing process will experience a statistically significant reduction in the removal torque compared to the non-induction sealing process. Second, during a time study, it is predicted that the induction sealed bottle/closure systems will experience a statistically significant increase in removal torque. Third, for bottle/closure systems that undergo retorquing after the induction sealing process, it is predicted that the samples will lose removal torque over time.

1.3 Literature Review

Many factors affect the bottle/closure removal torques such as the application torque, temperature, and time. Due to the viscoelastic nature of plastic bottles and caps, the removal torque is usually lower than that of the application (Soroka 2002). When applying a specific torque, it is to be expected that the removal torque be lower than that of the application torque for plastic bottles/cap systems. It was found, on average, for high density polyethylene (HDPE) containers with a 28 mm continuous thread cap and shallow 400 finishes could lose up to 54% of the application torque (Thompson 1999). To understand the application torque and removal relationship further, this thesis will investigate other closures; specifically, 33mm CR closure, 38mm CR closure, and 38mm CT closure.

In 2005, Michael Borchers wrote a Master's thesis on the effect of temperature on the removal torque of discontinuous-thread plastic closures (Borchers 2005). He concluded that HDPE containers and polypropylene (PP) discontinuous-thread caps that were exposed to high temperature experienced a significant reduction of removal torque. Bottles and caps that were exposed to low temperature compared to ambient conditions had a higher removal torque. The mixture of low/high temperature had the same effect on the removal as that of high temperature (Borchers 2005).

In a study conducted in 1999 by Ching-Sung and Gerald Greenway on the effect of time on cap removal torque using 20 oz polyethylene terephthalate (PET) bottles and 28mm finish caps with a vinyl liner, it was discovered that at any application torque, removal torque increased for the first ten days, then decreased slowly (Lai and Greenway 1999). They concluded that the interaction between the liner and finish caused the adhesion to become stronger and a high torque is required to open it. As time increased beyond 10 days, the interaction became weaker thus the removal torque decreased (Lai and Greenway 1999). The study mentioned was performed without induction sealing. For this thesis, removal torque will be studied over time after the induction sealing process to verify the hypotheses that over time, the induction sealed bottle/closure systems will experience a statistically significant increase in removal torque.

This thesis will contribute to the further understanding of factors affecting bottle/closure systems used in the pharmaceutical industry.

2 Method

The method used for the experiments were measurements (application torque measurements - the covariate - and the removal torque measurements - the response) obtained from the Sure Torque Tester, Model: ST-120 with reading precision of X.X in-lb by following the instructions provided in the operational manual.

Three experiments were performed to address the three hypotheses mentioned above. To address the first hypothesis (samples undergoing induction sealing process will experience a statistically significant reduction in the removal torque compared to the non-induction sealing process), the first experiment was conducted with samples that were induction sealed and samples that were not induction sealed. The removal torques of the induction and non-induction seal samples were then compared.

To address the second hypothesis (induction sealed bottle/closure systems will experience a statistically significant increase in removal torque), the second experiment was conducted with bottle/closure systems that went through the induction sealing process followed by removal torque measurements over time (within ten minutes, one day, one week, and two weeks).

To address the third hypothesis (bottle/closure systems that undergo retorquing after the induction sealing process will lose removal torque over time), the third experiment was conducted with 190cc bottle/38mm CR closure system. The bottle/closure system underwent induction sealing, followed by retorquing. The removal torque measurements were taken within ten minutes and one day.

3 Experiment

3.1 Test Materials

Three bottle/closure systems were used in the experiment. The first system was 75cc high density polyethylene (HDPE) and 33mm child resistant (CR) closure with liner and bottles. The second system was 190cc HDPE bottles and 38mm CR closures with liner. The third system was 190cc HDPE bottles and 38mm continuous thread (CT) closures with liner. The bottles and closures were manufactured by Rexam and Berry Plastics (formerly Kerr), respectively. The cap liner was made out of pulpboard, aluminum foil, and polyethylene (PE) film. The liner was manufactured by Unipac. Detail specifications are listed in Table 1, 2, and 3.

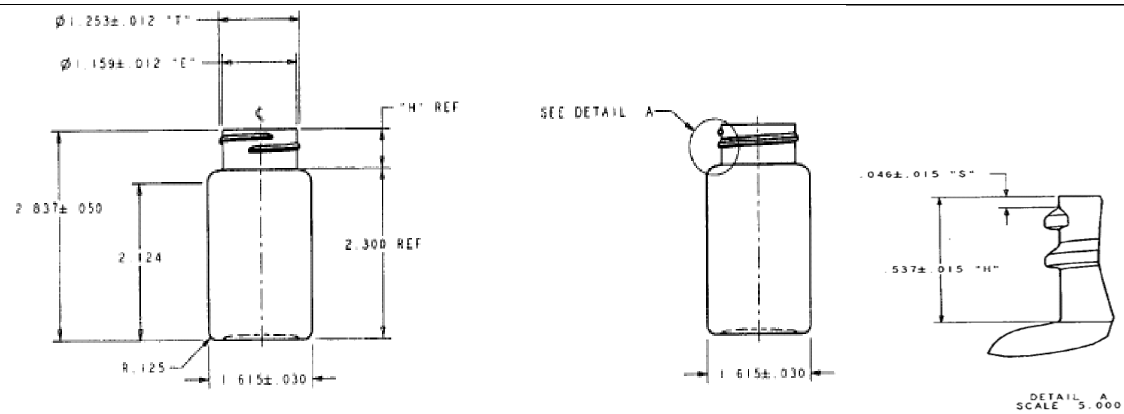
Table 1: Bottle and closure specifications – 75cc bottle/33mm CR closure system

75cc HDPE Square Bottle specifications

Finish: SPI 33-400, white

Dimensions: T: 1.253 ±0.012”, E: 1.159±0.012”, H: 0.537±0.015”,Width: 1.615±0.030” Depth: 1.615±0.030”, Height: 2.837 ±0.050”

Manufacturer: Rexam



33mm HDPE Child Resistant (CR) Closure specifications

Inner Cap: T: 1.268 ±0.007”, E: 1.200 ±0.007”, H: 0.390 ±0.009”

Outer Cap: Diameter at top 1.51”, Diameter at opening: 1.535”, Height: 0.684”

Cap Manufacturer: Berry Plastics

Liner: Pulpboard: 0.035” ±0.0035”, Micorcrystalline Wax: 0.00045”, Aluminum Foil: 0.001” , Polyethylene Film: 0.0015”, Total Liner Thickness: 0.04” ±0.005

Manufacturer: Unipac Safe-Gard 100

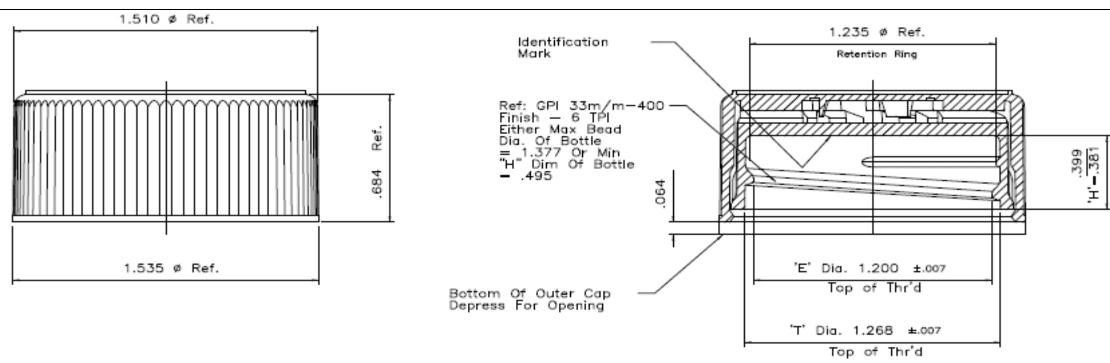


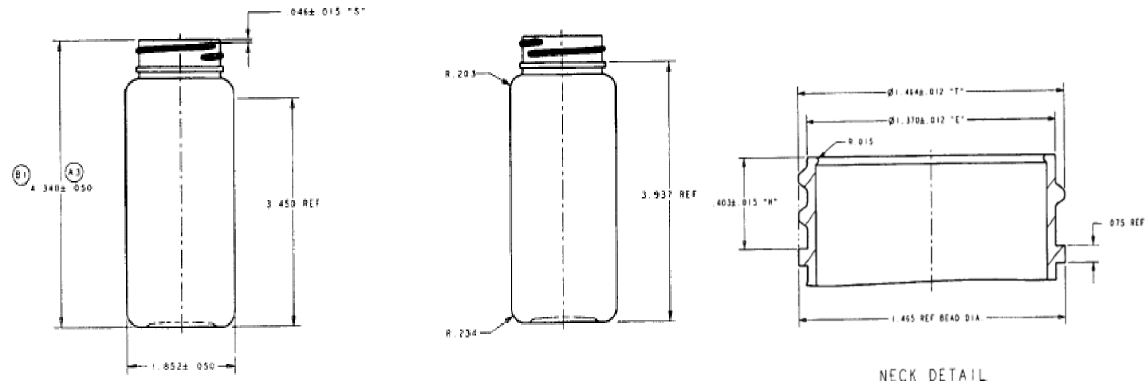
Table 2: Bottle and closure specifications – 190cc bottle/38mm CR closure system

190cc HDPE Square Bottle specifications

Finish: Finish: SPI 38-400, white

Dimensions: T: 1.464±0.012”, E: 1.370±0.012”, H: 0.403±0.015”, Width: 1.852±0.050”, Depth: 1.852±0.050”, Height: 4.340±0.050”

Manufacturer: Rexam



38mm HDPE Child Resistant (CR) Closure specifications

Inner Cap: T: 1.483 ±0.007”, E: 1.401 ±0.007”, H: 0.390 ±0.009”

Outer Cap: Diameter at top: 1.718”, Diameter at opening: 1.731”, Height: 0.706”

Cap Manufacturer: Berry Plastics

Liner: Pulpboard: 0.035” ±0.0035”, Micorcrystalline Wax: 0.00045”,
Aluminum Foil: 0.001” , Polyethylene Film: 0.0015”,
Total Liner Thickness: 0.04” ±0.005

Liner Manufacturer: Unipac Safe-Gard 100

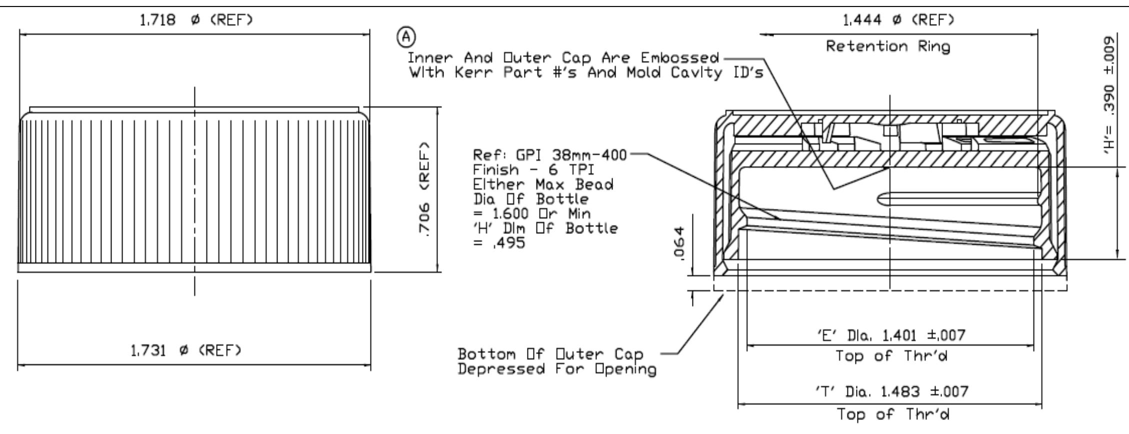
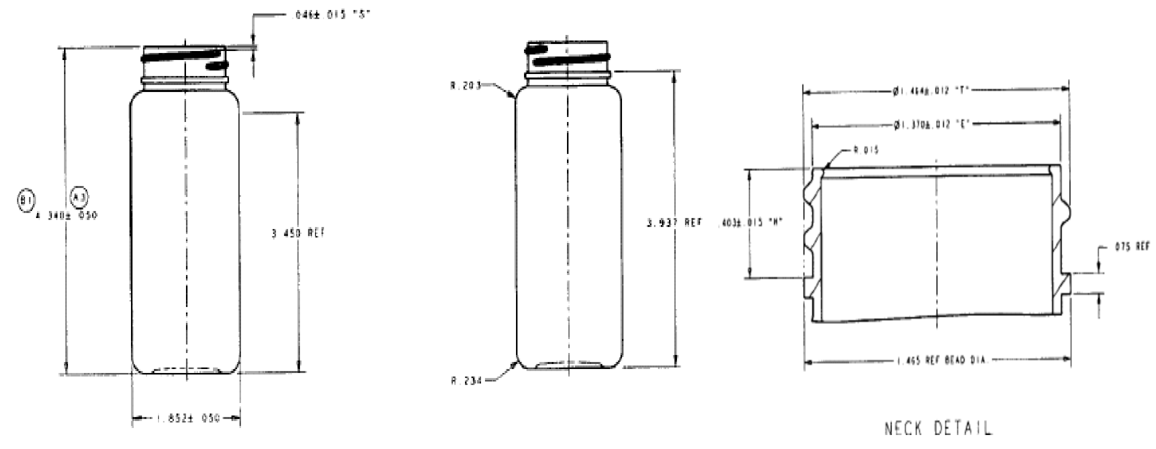
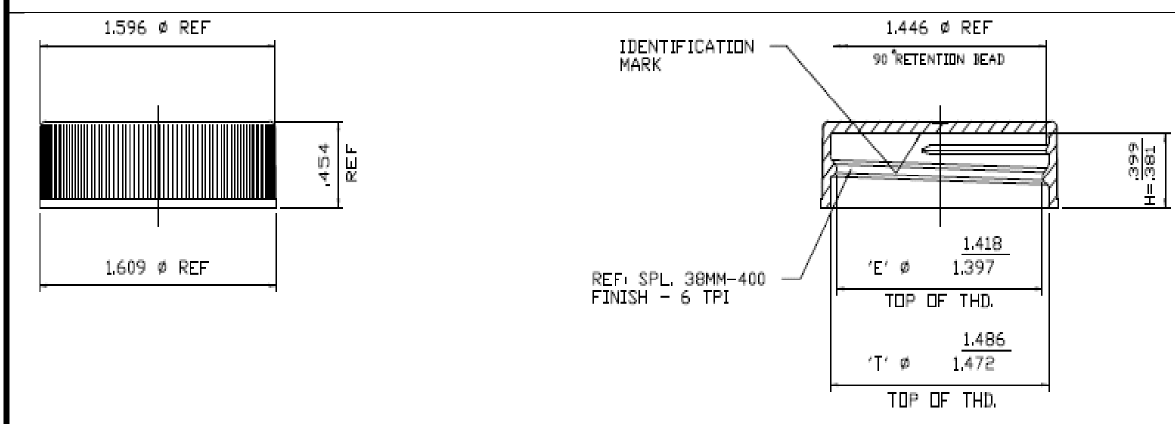


Table 3: Bottle and closure specifications – 190cc bottle/38mm CT closure system

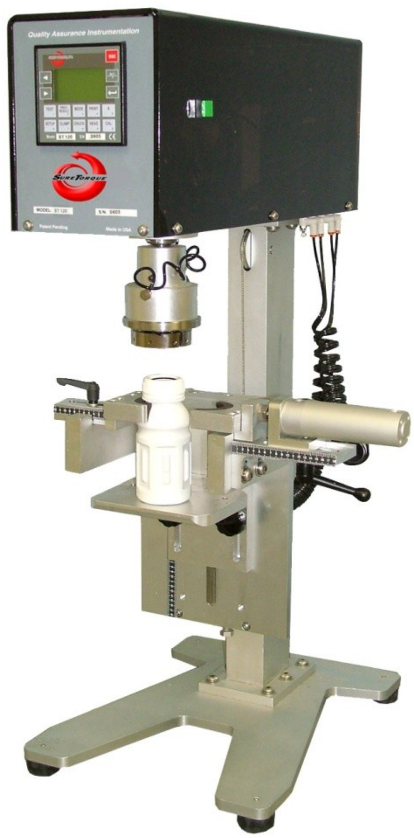
190cc HDPE Square Bottle specifications
Finish: Finish: SPI 38-400, white **Dimensions:** T: 1.464±0.012", E: 1.370±0.012", H: 0.403±0.015", Width: 1.852±0.050", Depth: 1.852±0.050", Height: 4.340±0.050"
Manufacturer: Rexam

38mm HDPE Continuous Thread (CT) Closure specifications
Inner Cap: T: 1.472 to 1.486", E: 1.397" to 1.418", H: 0.381" to 0.399"
Outer Cap: Diameter at top: 1.596", Diameter at opening: 1.609", Height: 0.454"
Cap Manufacturer: Berry Plastics
Liner: Pulpboard: 0.035" ±0.0035", Micorcrystalline Wax: 0.00045", Aluminum Foil: 0.001" , Polyethylene Film: 0.0015", Total Liner Thickness: 0.04" ±0.005
Liner Manufacturer: Unipac Safe-Gard 100


3.2 Test Equipment

3.2.1 Torque Tester

A Sure Torque Tester (Figure 1), Model: ST-120 was used to apply the application torque and to read the removal torque values. It was calibrated to the manufacturer's recommendation within the 6 months interval prior to use. Change parts specific to the bottles/closures were used for the specific bottles/closures combinations.

Figure 1: Sure Torque Tester
(Source: http://www.suretorque.com/downloads/support/Specifications/Specs-ST-120.pdf)



3.2.2 Induction Sealer

The induction sealer (Figure 2) used for the experiments is a magnetic induced sealer. The manufacturer is Enercon and the model number is LM4252-02. When the bottle/closure with liner passes underneath the induction sealer, it creates the tamper-evident feature on the top of the bottle. Power setting and the sealer head height can be adjusted.

Figure 2: Induction Sealer
(Source: http://www.enerconind.com/Sealing/Products/Super-Seal.aspx)

3.2.3 Conveyor

The conveyor moved the capped bottles from capper through the induction sealer. The speed of the conveyor was adjustable, and was calibrated prior to the experiments. The speed of the conveyor determined the amount time that the capped bottles stayed under the induction sealer.

If the capped bottles received insufficient power and the conveyor moved too fast, the seal would not bond sufficiently with the rim of the bottle, causing it to peel away in a manner that did not leave any tamper-evident residue. On the other hand, if the capped bottles received too much power, the roof of the cap began to burn, leading to visible charring. The optimal parameters of the induction sealer and conveyor were established prior to the performance of the experiments (see Table 4 below).

Table 4: Optimal Parameters

Bottle	Closure	Induction Power	Conveyor Speed Setting	Induction Sealer height
75cc HDPE	33mm CR	75%	80 ft/min	3/9”
190cc HDPE	38mm CR	75%	80 ft/min	3/9”
190cc HDPE	38mm CT	65%	80 ft/min	3/9”

3.3 Experiment 1: Effect of induction sealing on removal torque

The first experiment was a 3 X 2 full factorial experiment with respect to bottle/closure systems and induction seal status. For each treatment (factor and level), 20 independent application torques and 20 independent removal torque measurements were obtained. The application torque with a target value of 19.0 in-lb was utilized. To account for the application torque variation across the units, the measured application torque was used as a covariate in the statistical model. The removal torque was the response. Table 5 is a summary of the investigated factors and the corresponding levels.

Table 5: Experiment 1, Investigated Factors and Corresponding Levels

Factors	Levels
Bottle/Closure System	• 75cc bottle/33mm CR closure • 190cc bottle/38mm CR closure • 190cc bottle/38mm CT closure
Induction Seal Status	• No • Yes

For the non-induction bottle/closure systems, a hand capped bottle was placed on the Torque Tester. The tester applied the pre-set application of 19.0 in-lb torque to the capped bottle. The applied torque values were recorded. To obtain the immediate removal torque, 10 minutes or less, the capped bottle was placed back on the tester to obtain the removal torque. The removal torque values were recorded.

The same procedure was followed for the induction sealed bottle/closure systems, with the added step of placing the bottle/closures on the conveyor to go through the induction sealer after the application torque, followed by removal torque measurements.

This experiment procedure was conducted on the following bottle/closure systems: 75cc bottle/33mm CR closure (see Table 6), 190cc bottle/38mm CR closure (see Table 7), 190cc bottle /38mm CT closure (see Table 8).

Table 6: Experiment 1 Data, 75cc bottle/33mm CR closure system

Application torque (in-lb)	Removal torque (not induction sealed) within 10min (in-lb)		Application torque (in-lb)	Removal torque (Induction Sealed) within 10min (in-lb)
19.0	13.2		19.2	5.8
19.0	14.1		19.2	4.9
19.2	13.7		19.2	5.6
19.3	14.1		19.3	5.6
19.2	14.9		19.1	5.1
19.1	15.2		19.1	5.4
19.2	14.0		19.2	5.7
19.1	14.6		19.3	5.6
19.2	13.8		19.3	5.1
19.2	14.6		19.1	5.6
19.0	15.6		19.3	7.6
19.2	14.2		19.1	6.0
19.0	14.3		19.1	5.9
19.1	15.0		19.1	5.8
19.2	14.5		19.0	5.5
19.1	14.8		19.4	5.6
19.1	14.3		19.3	5.3
19.0	14.3		19.1	5.9
19.2	14.6		19.3	6.5
19.4	15.6		19.3	6.1

Table 7: Experiment 1 Data, 190cc bottle /38mm CR closure system

Application torque (in-lb)	Removal torque (not induction sealed) within 10min (in-lb)		Application torque (in-lb)	Removal torque (Induction Sealed) within 10min (in-lb)
19.0	14.4		19.1	4.5
19.0	15.3		19.1	4.7
19.0	13.3		19.2	5.5
19.0	16.1		19.0	4.6
19.1	12.3		19.0	4.7
19.1	14.4		19.1	4.4
19.1	14.5		19.2	4.6
19.2	15.0		19.3	5.3
19.2	14.5		19.1	3.7
19.0	12.7		19.0	5.1
19.3	18.6		19.0	5.0
19.0	15.4		19.2	5.3
19.0	16.3		19.0	5.4
19.0	15.2		19.1	5.3
19.1	15.4		19.2	4.9
19.2	13.3		19.1	5.0
19.2	13.9		19.0	5.3
19.1	14.0		19.0	5.3
19.0	15.5		19.1	5.1
19.1	14.7		19.0	5.1

Table 8: Experiment 1 Data, 190cc bottle/38mm CT closure system

Application torque (in-lb)	Removal torque (not induction sealed) within 10min (in-lb)		Application torque (in-lb)	Removal torque (Induction Sealed) within 10min (in-lb)
19.1	13.3		19.2	4.5
19.0	15.2		19.1	4.1
19.0	13.7		19.1	3.9
19.1	16.5		19.1	3.8
19.1	15.8		19.1	3.7
19.0	16.6		19.0	3.8
19.0	14.4		19.2	3.9
19.0	12.9		19.0	4.5
19.2	15.4		19.0	4.3
19.0	16.2		19.1	3.6
19.0	14.9		19.2	4.0
19.0	14.6		19.1	4.3
19.3	14.4		19.3	3.4
19.2	12.7		19.0	3.3
19.1	14.3		19.0	4.5
19.1	14.0		19.1	4.4
19.2	13.6		19.5	3.9
19.0	13.3		19.1	4.2
19.2	13.9		19.1	4.1
19.2	15.5		19.1	3.7

3.4 Experiment 2: Effect of time on the removal torque of induction sealed bottle/closure with no retorquing

The second experiment was a 3 X 4 full factorial experiment (see Table 9 below) with respect to bottle/closure systems and time study. For each treatment (factor and level), 20 independent application torques and 20 independent removal torque measurements were obtained. The application torque with a target value of 19.0 in-lb was utilized. To account for the application torque variation across units, the measured application torque was used as a covariate in the statistical model. The removal torque was the response.

Table 9: Experiment 2 Data, Investigated Factors and Corresponding Levels

Factors	**Levels**
Bottle/Closure System	• 75cc bottle/33mm CR closure • 190cc bottle/38mm CR closure • 190cc bottle/38mm CT closure
Induction Seal Status	• Induction Seal Removal torque within 10 min • 24 hours • 11 day • 2 weeks

Prior to the start of this experiment, the induction sealer height, conveyor speed and induction sealer power were determined to obtain the proper induction seal (refer to Table 4 for settings). The hand capped bottle was placed on the Torque Tester. The application torque values were recorded. The capped bottles were then placed on the conveyor to go through the induction sealer. This experiment procedure was used for the following bottle/closure systems: 75cc bottle/33mm CR closure, 190cc bottle/38mm CR closure, 190cc bottle/38mm CT closure.

Starting with 75cc bottle/33mm CR closure system, the induction sealed capped bottle was removed downstream of the induction sealer and collected. Of the 100 bottles collected, 20 random bottles were selected for reading within ten minutes. The rest of the bottles were set aside until the assigned time was reached (24 hours, 11 days, and 2 weeks). When the assigned time was reached, 20 bottles were randomly selected from the population to obtain the removal torque values. The removal torque values were recorded. Refer to Table 10, 11, and 12 for 75cc bottle/33mm CR closure, 190cc bottle/38mm CR closure, and 190cc bottle/38mm CT closure data respectively.

Table 10: Experiment 2 Data, 75cc bottle/33mm CR closure system
A.T = Application Torque (in-lb), R.T = Removal Torque (in-lb)

Time of R.T	A.T	R.T		A.T	R.T		A.T	R.T		A.T	R.T
Within 10min	19.2	5.8		19.1	5.4		19.3	7.6		19.4	5.6
	19.2	4.9		19.2	5.7		19.1	6.0		19.3	5.3
	19.2	5.6		19.3	5.6		19.1	5.9		19.1	5.9
	19.3	5.6		19.3	5.1		19.1	5.8		19.3	6.5
	19.1	5.1		19.1	5.6		19.0	5.5		19.3	6.1
24 hours	19.0	6.4		19.2	6.6		19.0	6.2		19.0	6.4
	19.1	6.6		19.0	6.6		19.2	6.9		19.0	5.6
	19.3	6.1		19.2	6.0		19.0	6.8		19.1	6.7
	19.2	6.1		19.1	6.3		19.1	6.9		19.3	6.7
	19.2	6.4		19.1	6.2		19.1	6.1		19.1	4.9
11 days	19.2	7.8		19.1	6.8		19.2	6.8		19.0	6.9
	19.0	7.8		19.0	7.1		19.1	6.6		19.1	7.2
	19.1	6.9		19.3	7.2		19.1	7.2		19.1	5.9
	19.2	6.6		19.0	6.2		19.2	6.9		19.2	6.7
	19.0	7.3		19.2	7.4		19.1	6.7		19.1	6.7
2 weeks	19.2	7.0		19.1	7.1		19.2	6.7		19.0	7.2
	19.0	7.0		19.1	6.8		19.0	6.7		19.0	7.2
	19.4	7.5		19.0	7.4		19.3	6.8		19.1	7.2
	19.2	6.6		19.0	6.4		19.2	6.9		19.3	7.1
	19.4	7.5		19.2	8.3		19.0	6.9		19.3	7.1

Table 11: Experiment 2 Data, 190cc bottle/38mm CR closure system
A.T = Application Torque (in-lb), R.T = Removal Torque (in-lb)

Time	A.T	R.T		A.T	R.T		A.T	R.T		A.T	R.T
Within 10min	19.1	4.5		19.1	4.4		19.0	5.0		19.1	5.0
	19.1	4.7		19.2	4.6		19.2	5.3		19.0	5.3
	19.2	5.5		19.3	5.3		19.0	5.4		19.0	5.3
	19.0	4.6		19.1	3.7		19.1	5.3		19.1	5.1
	19.0	4.7		19.0	5.1		19.2	4.9		19.0	5.1
24 hours	19.0	6.3		19.2	6.2		19.2	5.9		19.0	5.0
	19.1	5.7		19.1	6.2		19.0	6.3		19.0	5.7
	19.1	5.9		19.0	6.5		19.0	6.4		19.0	5.8
	19.0	5.3		19.0	6.4		19.0	6.1		19.2	5.0
	19.0	6.3		19.2	5.8		19.0	5.7		19.0	6.0
11 days	19.2	6.3		19.0	5.7		19.2	5.6		19.2	5.3
	19.0	6.5		19.1	5.8		19.1	5.3		19.4	5.9
	19.2	6.1		19.1	5.1		19.0	5.5		19.2	5.8
	19.0	5.8		19.2	6.3		19.0	5.2		19.0	5.7
	19.3	5.6		19.0	6.4		19.3	6.4		19.2	5.9
2 weeks	19.0	7.1		19.2	6.7		19.2	7.3		19.0	7.7
	19.0	8.0		19.2	5.9		19.0	6.9		19.0	7.0
	19.0	6.4		19.0	7.3		19.2	7.6		19.2	7.2
	19.1	6.9		19.3	7.8		19.0	6.7		19.2	7.0
	19.1	7.2		19.1	8.4		19.1	7.1		19.0	6.7

Table 12: Experiment 2 Data, 190cc bottle/38mm CT closure system
A.T = Application Torque (in-lb), R.T = Removal Torque (in-lb)

Time	A.T	R.T		A.T	R.T		A.T	R.T		A.T	R.T
Within	19.2	4.5		19.0	3.8		19.2	4.0		19.1	4.4
10min	19.1	4.1		19.2	3.9		19.1	4.3		19.5	3.9
	19.1	3.9		19.0	4.5		19.3	3.4		19.1	4.2
	19.1	3.8		19.0	4.3		19.0	3.3		19.1	4.1
	19.1	3.7		19.1	3.6		19.0	4.5		19.1	3.7
	19.0	4.1		19.0	4.1		19.0	3.7		19.0	3.6
24 hours	19.1	4.5		19.1	3.8		19.2	3.8		19.0	4.4
	19.0	4.6		19.1	3.9		19.2	3.8		19.3	4.6
	19.2	4.4		19.0	4.0		19.4	3.7		19.0	4.0
	19.4	3.9		19.2	4.4		19.0	3.8		19.0	3.1
	19.0	4.7		19.1	4.6		19.2	5.2		19.0	4.2
11 days	19.1	4.6		19.2	4.6		19.2	4.7		19.2	4.9
	19.1	4.4		19.1	4.7		19.0	4.7		19.1	4.5
	19.0	4.6		19.0	5.3		19.2	4.9		19.0	5.0
	19.1	4.8		19.1	4.2		19.3	4.7		19.2	4.8
	19.1	5.4		19.2	5.4		19.3	5.3		19.2	5.2
2 weeks	19.1	5.4		19.0	5.5		19.0	4.7		19.0	5.1
	19.1	4.8		19.0	4.9		19.0	4.9		19.1	4.5
	19.0	4.8		19.1	5.0		19.2	4.7		19.1	5.4
	19.0	5.7		19.2	5.0		19.0	5.1		19.0	5.6

3.5 Experiment 3: Effect of time on the removal torque of induction sealed bottle/closure subjected to retorquing

The third experiment was a completely randomized design (CRD) experiment utilizing time as the factor with the level of 10 minutes or less and 24 hours. For each treatment, 20 bottles were evaluated.

The 190cc bottle/38mm CR closure system, hand capped bottle was placed on the Torque Tester. The application torque values were recorded. The capped bottles were then placed on the conveyor to go through the induction sealer. The induction sealed bottles were then placed on the Sure Torque to retorque the bottles to 10 in-lb. 40 retorqued bottles were set aside. Of the 40 bottles, 20 bottles were randomly selected for removal torque measurement within 10 minutes. The rest of the bottles were set aside until 24 hour later. The removal torque readings were recorded. Refer to Table 13 for the data.

Table 13: Experiment 3 Data, Retorqued, 190cc bottle/38mm CR closure system

	Torque Value (in-lb)						
Time	**Applied**	**Retorque**	**Removal**		**Applied**	**Retorque**	**Removal**
Within 10min	19.2	10.1	8.9		19.2	10.0	9.8
	19.2	10.0	8.4		19.2	10.2	8.3
	19.0	10.1	8.5		19.1	10.0	9.5
	19.0	10.2	8.7		19.2	10.1	8.5
	19.1	10.0	10.0		19.1	10.2	8.9
	19.2	10.1	8.8		19.0	10.1	8.1
	19.2	10.1	8.9		19.1	10.1	10.1
	19.1	10.3	7.7		19.1	10.0	9.9
	19.0	10.0	7.8		19.0	10.0	9.0
	19.0	10.2	9.0		19.2	10.1	8.2
24 hours	19.0	10.0	6.8		19.0	10.2	7.0
	19.0	10.1	7.4		19.1	10.1	7.3
	19.0	10.0	8.2		19.1	10.0	7.6
	19.0	10.1	6.9		19.0	10.2	8.0
	19.1	10.0	7.5		19.0	10.3	8.2
	19.1	10.0	8.5		19.1	10.1	7.0
	19.0	10.1	9.1		19.2	10.2	7.8
	19.0	10.1	8.3		19.1	10.1	8.0
	19.1	10.1	8.1		19.0	10.1	6.8
	19.0	10.0	9.1		19.2	10.0	8.0

4 Data Analysis

4.1 Experiment 1: Effect of induction sealing on removal torque

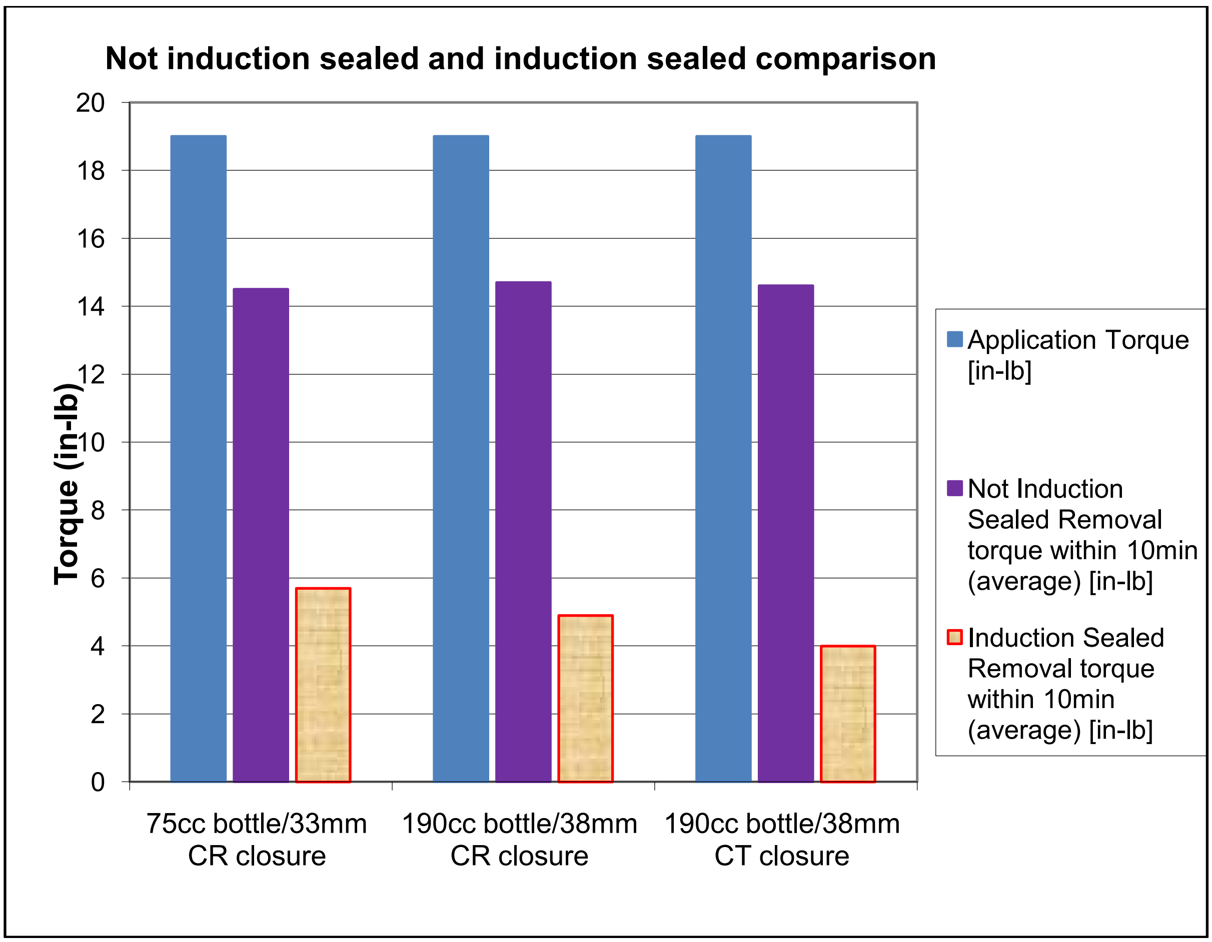
An analysis of covariance for Experiment 1 was performed with application torque as the covariate and the effect of bottle/closure systems, induction sealing status, and corresponding interaction as factors. The non-induction seal average removal torque for 75cc bottle/33mm CR closure, 190cc bottle/38mm CR closure, 190cc bottle/38mm CT closure were 14.5 in-lb, 14.8 in-lb, and 14.6 in-lb, respectively. The induction seal average removal torque for 75cc bottle/33mm

CR closure, 190cc bottle/38mm CR closure, 190cc bottle/38mm CT closure were 5.7 in-lb, 5.0 in-lb, and 4.0 in-lb, respectively. Refer to Table 14 below and Figure 3 below.

Table 14: Experiment 1 Data Analysis – Not Induction Sealed and Induction Sealed Removal Torques

Induction seal status	Bottle/Closure System	Least Square Means Removal Torque [in-lb]	95% confidence interval [in-lb]
No	75cc/33mmCR	14.5	[14.1, 14.8]
No	190cc/38mmCR	14.8	[14.4, 15.1]
No	190cc/38mmCT	14.6	[14.2, 15.0]
Yes	75cc/33mmCR	5.7	[5.3, 6.1]
Yes	190cc/38mmCR	5.0	[4.6, 5.3]
Yes	190cc/38mmCT	4.0	[3.6, 4.4]

Figure 3: Not Induction Sealed and Induction Sealed Bottles/Closures removal torques comparison



Across the three non-induction systems, there was no statistical significance (Table 15 below). However, there was a statistical significance across the three systems that were induction sealed (Table 16 below).

Table 15: Experiment 1 Data Analysis, P-value, not induction sealed, comparison across bottle/cap systems

	190cc/38mmCR	**190cc/38mmCT**
75cc/33mmCR	0.2933	0.6955
190cc/38mmCR		0.5027

Table 16: Experiment 1 Data Analysis, P-value, induction sealed, comparison across bottle/cap systems

	190cc/38mmCR	**190cc/38mmCT**
75cc/33mmCR	0.0091	<.0001
190cc/38mmCR		0.0006

Comparing the non-induction systems and induction sealing systems, there were statistically significant drops in the average removal torque values (Table 17) for the p-value. The estimated average decrease of removal torque values across the non-induction and induction seal were 8.8 in-lb, 9.8 in-lb, and 10.6 in-lb for 75cc bottle/33mm CR closure, 190cc bottle/38mm CR closure, 190cc bottle/38mm CT closure, respectively (Table 18).

Table 17: Experiment 1 Data Analysis, P-value, comparison across non-induction seal and induction seal bottle/cap systems

	75cc/33mmCR Induction Sealed	190cc/38mmCR Induction Sealed	190cc/38mmCT Induction Sealed
75cc/33mmCR Non-induction Sealed	<.0001	<.0001	<.0001
190cc/38mmCR Non-induction Sealed		<.0001	<.0001
190cc/38mmCT Non-induction Sealed			<.0001

Table 18: Experiment 1 Data Analysis, estimated average decrease of removal torque for non-induction seal and induction seal bottle/closure systems

System	Estimated average decreased of removal torque from non-induction seal to induction seal	95% confidence interval
75cc/33mmCR	8.8	[8.2, 9.3]
190cc/38mmCR	9.8	[9.3, 10.3]
190cc/38mmCT	10.6	[10.0, 11.1]

For the three bottle/closure systems, the results are summarized in Table 19 below. For the 75cc bottle/33mm CR closure system, the average removal torque dropped to a removal torque of 5.7 in-lb after the induction seal process; a drop of 60.7%. For the 190cc bottle/38mm CR closure system, the average removal torque dropped to 5.0 in-lb after the induction sealed process; a drop of 66.2%. For the 190cc bottle/38mm CT closure system, with the application torque of 19.0 in-lb, the average removal torque dropped to 4.0 in-lb after induction seal process; a drop of 72.6%. For all three systems in this study, the induction sealing process affected the removal torque. Specifically, the induction sealing process lowered the removal torque compared to that of the non-induction process.

Table 19: Comparison of removal torque between not induction sealed and induction sealed bottle/closure systems

	75cc bottle/33mm CR closure	**190cc bottle/38mm CR closure**	**190cc bottle/38mm CT closure**
Not Induction Sealed: Removal torque within 10min (least square means) [in-lb]	14.5 (23.7% torque reduction compared to application of 19.0 in-lb)	14.8 (22.1% torque reduction compared to application of 19.0 in-lb)	14.6 (23.2% torque reduction compared to application of 19.0 in-lb)
95% confidence interval	[14.1, 14.8]	[14.4, 15.1]	[14.2, 15.0]
Induction Sealed: Removal torque within 10min (average) [in-lb]	5.7 (60.7% torque reduction compared to non-induction seal)	5.0 (66.2% torque reduction compared to non-induction seal in-lb)	4.0 (72.6% torque reduction compared to non-induction seal in-lb)
95% confidence interval	[5.3, 6.1]	[4.6, 5.3]	[3.6, 4.4]

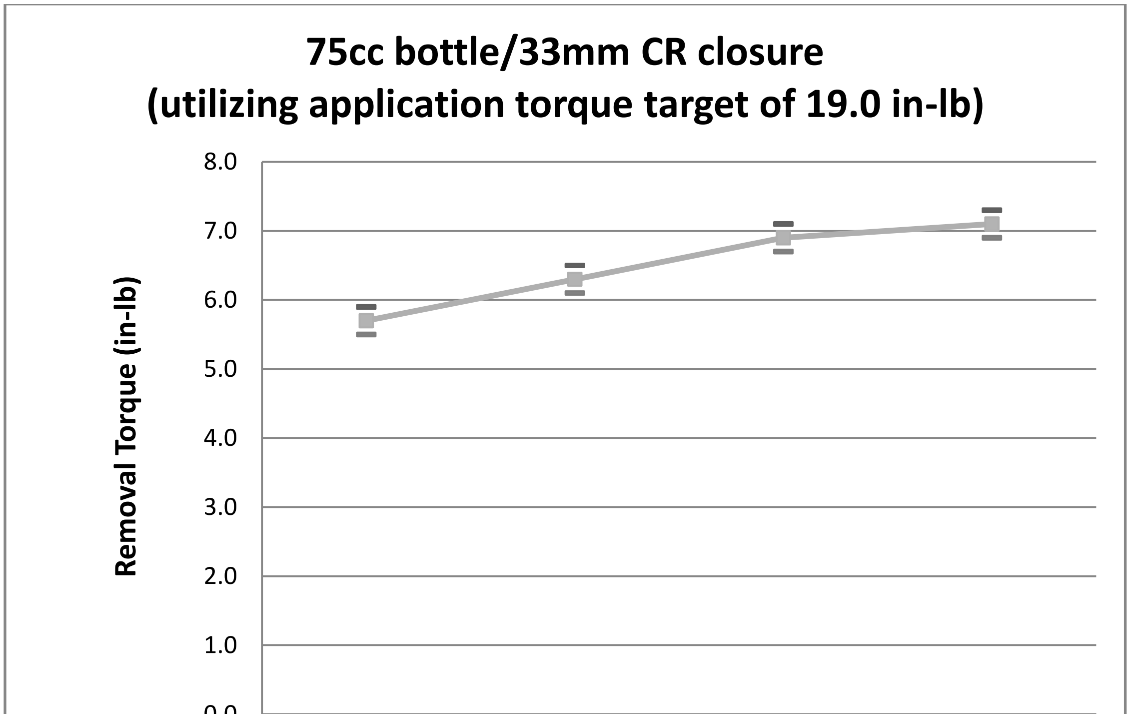
4.2 Experiment 2: Effect of time on the removal torque of induction sealed bottle/closure with no retorquing

An analysis of covariance was performed for Experiment 2 with application torque as the covariate and the effect of bottle/closure systems, effect of time, and corresponding interaction as factors.

4.2.1 Experiment 2: Effect of time - 75cc bottle/33mm CR closure system

As shown in Figure 4 and Table 20 below, there was a statistically significant difference from 10 minutes to 24 hours for the 75cc bottle/33mm CR closure system. The average removal torque value increased from 5.7 in-lb to 6.3 in-lb during this time period. There was a statistically significant difference from 24 hours to 2 weeks for the 75cc bottle/33mm CR closure system; the average torque value increased from 6.3 in-lb to 7.1 in-lb. The average removal torque also increased from 6.3 in-lb to 7.1 in-lb. From 10 minutes to 2 weeks, the average torque value increased from 5.7 in-lb to 7.1 in-lb, or a 24.5% increase of removal torque.

Figure 4: Experiment 2 Data Analysis, 75cc bottle/33mm CR closure system



	Induction Seal Removal torque with 10min	24 hours	11 days	2 week
95% Confidence limit (upper)	5.9	6.5	7.1	7.3
Average	5.7	6.3	6.9	7.1
95% Confidence limit (lower)	5.5	6.1	6.7	6.9

Table 20: Experiment 2 Data Analysis, 75cc bottle/33mm CR closure system p Value

	24 hours	11 day	2weeks
Induction seal removal torque within 10 min	<0.0001	<0.0001	<0.0001
1 day		<0.0001	<0.0001
11 day			0.3725

4.2.2 Experiment 2: Effect of time - 190cc bottle/38mm CR closure system

As shown in Figure 5 and Table 21, there was a statistically significant difference from 10 minutes to 24 hours for the 190cc bottle/38mm CR closure system. The average removal torque value increased from 4.9 in-lb to 5.9 in-lb during this time period. There was a statistically significant difference from 24 hours to 2 weeks for the 190cc bottle /38mm CR closure system. The average removal torque value increased from 5.9 in-lb to 7.1 in-lb. From 10 minutes to 2 weeks, the average torque increased from 4.9 in-lb to 7.1 in-lb, or a 44.9% increase of removal torque.

Figure 5: Experiment 2 Data Analysis, 190cc bottle/38mm CR closure system

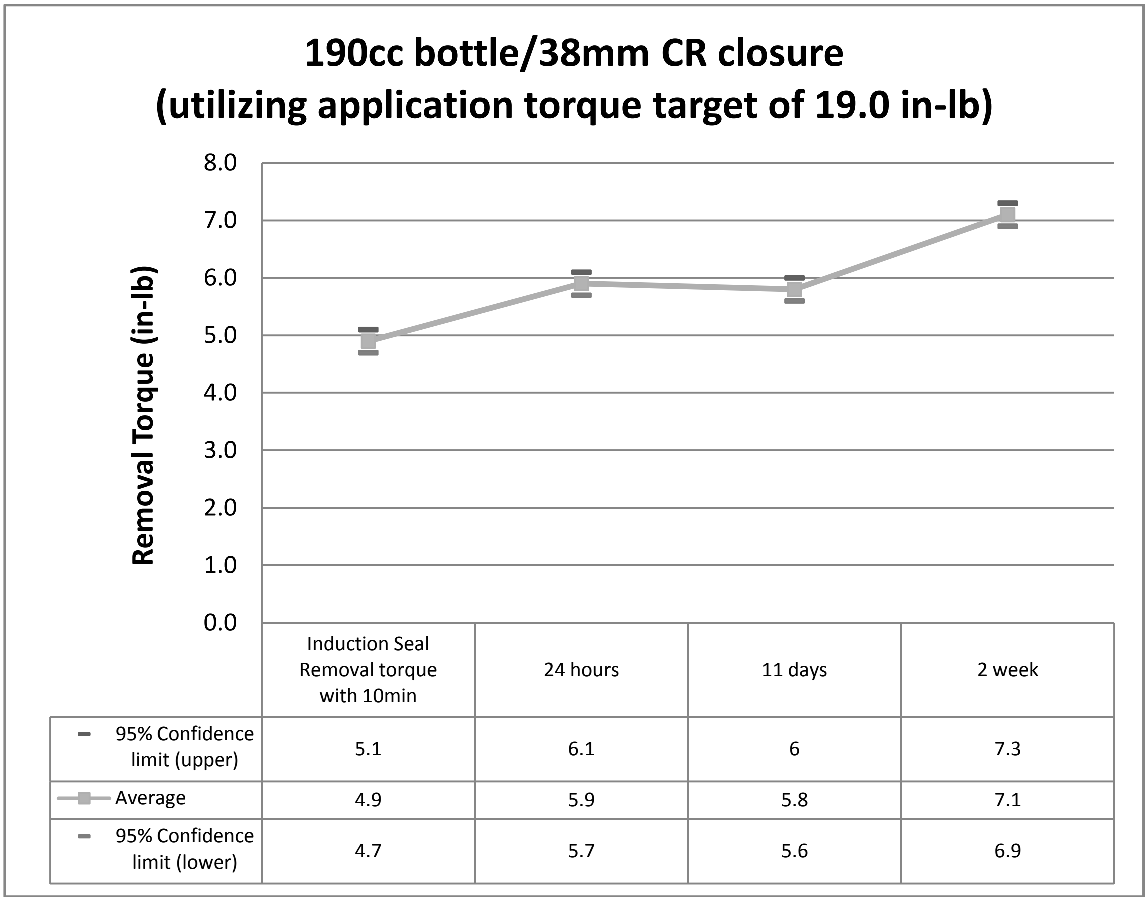


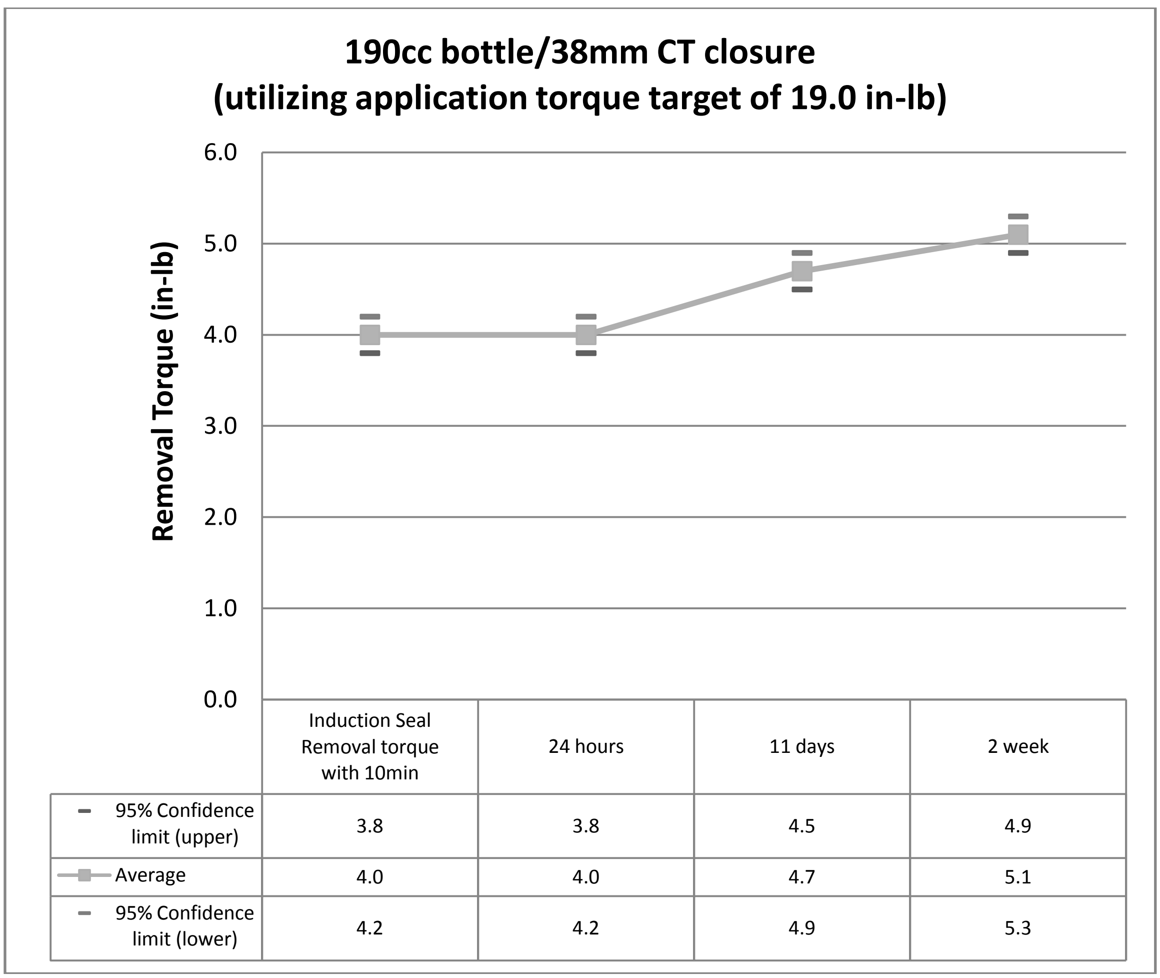
Table 21: Experiment 2 Data Analysis, 190cc bottle/38mm CR closure system p Value

	24 hours	11 day	2weeks
Induction seal removal torque within 10 min	<0.0001	<0.0001	<0.0001
1 day		0.3074	<0.0001
11 day			<0.0001

4.2.3 Experiment 2: Effect of time - 190cc bottle/38mm CT closure system

As shown in Figure 6 and Table 22, there was no statistically significant difference from 10 minutes to 24 hours for the 190cc bottle/38mm CT closure system. The average removal torque was 4.0 in-lb during this time period. There was a statistically significant difference from 24 hours to 2 weeks for the 190cc bottle/38mm CT closure system. The average removal torque increased from 4.0 in-lb to 5.1 in-lb. From the 10 minutes to 2 weeks, the average torque increased from 4.0 in-lb to 5.1 in-lb, or a 27.5% increase of torque.

Figure 6: Experiment 2 Data Analysis, 190cc bottle/38mm closure CT system



	Induction Seal Removal torque with 10min	24 hours	11 days	2 week
95% Confidence limit (upper)	3.8	3.8	4.5	4.9
Average	4.0	4.0	4.7	5.1
95% Confidence limit (lower)	4.2	4.2	4.9	5.3

Table 22: Experiment 2 Data Analysis, 190cc/38mm CT system p Value

	24 hours	11 day	2weeks
Induction seal removal torque within 10 min	0.8938	<0.0001	<0.0001
1 day		<0.0001	<0.0001
11 day			0.0023

4.3 Experiment 3: Effect of time on the removal torque of induction sealed bottle/closure subjected to retorquing

Analysis of covariance was performed on Experiment 3 with application torque and retorque value as covariates and the effect of time as a factor.

4.3.1 Experiment 3: Retorquing impact - 190cc/38mm CR system

As shown in Figure 7 and Table 23, there was a statistically significant difference from 10 minutes to 1 day. The average removal torque value decreased from 8.9 in-lb to 7.8 in-lb.

Figure 7: Experiment 3 Data Analysis, 190cc bottle/38mm CR closure system, Retorqued

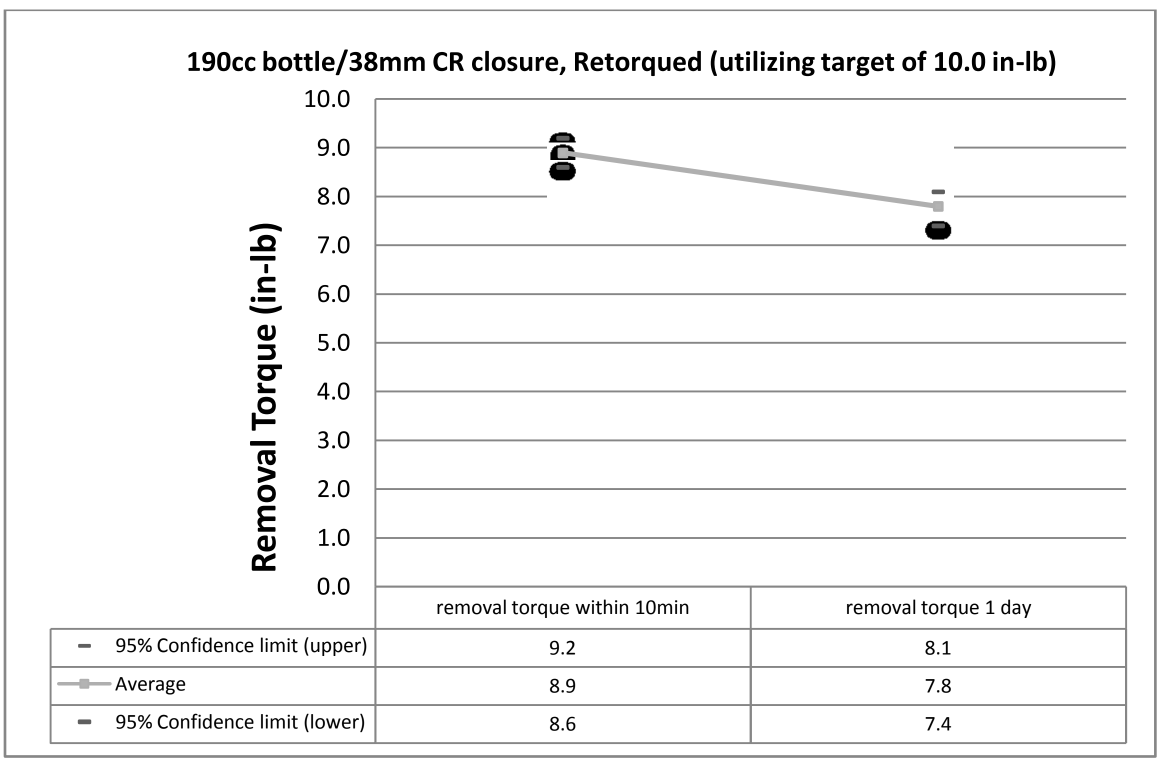


Table 23: Experiment 3 Data Analysis, 190cc/38mm CR system, Retorqued, p Value

	1 day
removal torque within 10 min	<0.0001

5 Conclusions

In conclusion, the induction sealing process affected the removal torque of all three systems under investigation, which confirmed the first hypothesis that samples undergoing an induction sealing process will experience a statistically significant reduction in the removal torque compared to the non-induction sealing process. The removal torque decreased by 60.7%, 66.2%, and 72.6% for 75cc bottle/33mm CR closure system, 190cc bottle/38mm CR closure system, and 190cc bottle/38mm CT closure system, respectively.

Immediately after the induction sealing, the removal torque is at its lowest point. After two weeks the removal torque increased by 24.5%, 44.9%, and 27.5% for 75cc bottle/33mm CR closure system, 190cc bottle/38mm CR closure system, and 190cc bottle/38mm CT closure system, respectively. This confirmed the second hypothesis that over time the induction sealed bottle/closure systems will experience a statistically significant increase in removal torque.

For the induction sealed and retorquing of 190cc bottle/38mm CR closure system, the removal torque decreases during the 1 day measurement, which partially confirmed the third hypothesis that samples that undergo retorquing after the induction sealing process will lose removal torque over time. However, further study is required to confirm if this would apply across all three bottle/closure systems and for a longer time period.

6 Further Recommended Study

Three further studies are recommended. The first, as mentioned above, a further study is recommended to confirm if all three bottle/closure systems that undergo retorquing after the induction sealing process would lose removal torque over a longer period of time.

This thesis investigated three bottle/closure systems with 19 in-lb as the application torque value; however, in a bottled line packaging operation, the automatic capper's application torque varies from chuck head to chuck head. The second recommended future study is to conduct an experiment with different sets of application torque values, and determine what the removal torque would be over the same period of time.

When comparing the retorquing and the non-retorquing of the 190cc bottle/38mm CR closure system, (Figure 8, Tables 24 and 25), there was an interesting observation. The retorqued 190cc bottle/38mm CR closure system started out at a higher removal torque of 8.9 in-lb and then decreased to 7.9 in-lb over a 1 day period, whereas the non-retorqued 190cc bottle/38mm CR closure system started at a lower removal torque value (4.9 in-lb) and then increased to a value of 5.9 in-lb over one day period. The third recommended study would be to determine if the retorqued and non-retorqued bottle/closure systems would converge over time.

Figure 8: Induction Sealed - Removal Torque: 190cc bottle/38mm CR closure system comparison between retorque and non-retorque

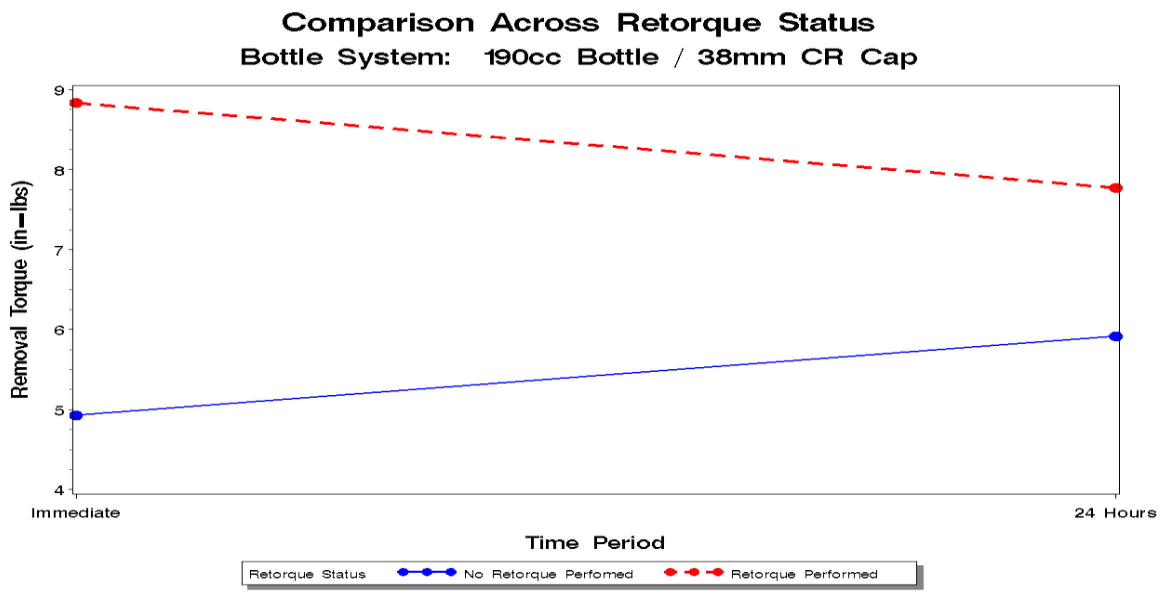


Table 24: 190cc/38mm CR system comparison between Retorque p Value

	24 hours
Immediate	<0.0001

Table 25: 190cc/38mm CR system comparison between Non-Retorque p Value

	24 hours
Immediate	<0.0001

7 References

Borchers Michael (2005). *Effect of temperature on removal torque of discontinuous-thread plastic closures.* Ann Arbor, MI: ProQuest Information and Learning Company. UMI 1429406

Chakraborti, Somumya (1996). *Effect of shipping orientation and closure type on leakers in gall size bottles.* Ann Arbor, MI: A Bell & Howell information Company. UMI 1381842

Giles, Geoff A. and Bain, David R. (2001). *The Techonology of Plastics Packaging for the Consumer Market"*, CRC Press LLC: Boca Raton, FL

Lai, Ching-Sung and Greenway, Gerald (1999). The effect of time on cap removal Torque. *Packaging Technology & Engineering. June 99, p 34, 3p*

Paine, F.A, (1991). *The Packaging User's Handbook*, New York: Blackie Academic & Professional.

Selke, Susan E.M. (1997). *Understanding Plastics Packaging Technology*, Munich:Carl Hanser Verlag.

Soroka, Walter (2002). *Fundamentals of Packaging Technology, the definitive resource on packaging technology.* 3rd edition, Naperville, Illinois: Institute of Packaging Professionals.

Thompson, Chad (1999). CT closure torque retention analysis key to seal, re-seal integrity. *Packaging Technology & Engineering. Feb 99, Vol.8 Issue 2, p 26, 4p*