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# EFFECT OF SHIPPING ORIENTATION AND CLOSURE TYPE ON LEAKERS IN GALLON SIZE BOTTLES

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## ABSTRACT

## EFFECT OF SHIPPING ORIENTATION AND CLOSURE TYPE ON LEAKERS IN GALLON SIZE BOTTLES

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This study investigated the effect of shipping orientation and closure type on leakers in gallon size bottles when subjected to the small parcel distribution environment. The bottle used was a 38-400 finish, round, gallon size HDPE. The closures used were one with a foamed LDPE core with top and bottom layers of 2 mil thick LDPE; a closure lined with induction foil; Pressure Sensitive adhesive lined closure. The bottles were filled with a gallon of water. After closing with the recommended application torque, six bottles with the same closure type were packaged in a single wall RSC type corrugated box. For each closure type 10 boxes were made. Out of these, 8 boxes were conditioned at 72°F, 50% RH for 72 hours. The other two boxes were inspected for immediate removal torque. After conditioning at normal conditions for 72 hours, 6 boxes were tested for vibration at resonance for 45 minutes in the large side down, the small side down, and the top face down orientations. The bottles were checked for removal torque. The results showed a significant reduction in torque after the bottles were subjected to vibration. The Sure-Seal type showed the maximum number of leakers from the finish. The total number of leakers was found to be maximum in the small side orientation due to the dynamic compression and flexing of the bottles.

I would like to dedicate this thesis to my parents and my beloved sister for their constant support and encouragement during this period.

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# 1.0 INTRODUCTION

The most critical part of a package is usually the closure. It ensures the integrity of the package during the assembly, storage, handling, and shipping and has to withstand various physical and climatic hazards. The security of the package assembly is also dependent on the closure. At the same time it must also be easy to open and close when it reaches the consumer.

A closure can sometimes enhance the aesthetic appeal of a package. It is often the extra finishing touch on the closure, like a golden embossed ring or a ribbon bow, that increases the perceived quality of the product in the market place and provides value to the customer. Thus, in order to find a prominent position in the dynamic and ever changing market place, the closure of a package often deserves a prominent position.

In the small parcel environment distribution system like UPS or Fed Ex, closures serve a very important purpose to protect the contents of packages. In this type of distribution system the packages are manually handled while loading and unloading. Also in order to achieve space utilization these packages are often sorted out and combined with other packages. Therefore evaluating the orientation of a package is a major consideration because of the Less Than Truck Load form of shipment.

The functions of closures and their impact in the small parcel environment will be discussed in this chapter.

## 1.1 ORIGIN OF CLOSURES

The origin and use of the closures in packages dates back in history. For a long time the human civilization has been using closures to preserve contents from spilling and contamination. The use of fabricated cork bottle stoppers can be found in the ancient Roman Empire dating back to 1660 when champagne was invented. It was also a popular method of closing wine bottles in Spain and Portugal. Other methods of sealing used in different parts of the world include glass stopples and various lids made of glass and clay used by the Western Europeans. Wax was another type of closure that was inserted into the neck and covered with leather or parchment. The high cellular density incompressibility and low thermal conductivity made cork an ideal choice as a closure material. By the mid-nineteenth century, cork was the predominant closure, providing a friction seal for a variety of products.

Bottles with threaded finishes are also known to have been used, although rarely because of the difficulty of making them, in the early nineteenth century. In 1858 John L Mason made an improvement in the design of thread on the glass container. He started the thread a little below the top surface and made it fade away before reaching the shoulder (Hanlon, 1992). This was the beginning of a new concept of threaded closure in the industry. With the advent of the age of automation in the beginning of twentieth century the demand for easy to use standardized closures was created. Bakelite was found to be an inexpensive option and emerged as a widely used material for closures. The plastic closures being expensive at that time were only used for premium products because they allowed for a freedom in design, color, and textures which made them aesthetically appealing. However, they were not as strong as metal caps and were susceptible to breakage. Today, nearly 10 billion plastic closures are annually used by the Packaging Industry in the United States (Hanlon, 1992). Most plastic closures used today are made of polypropylene.

Shortly after the development of Mason jar, William Painter of Baltimore obtained a patent on his newly invented Crown Cap. The crown cap seemed to be the ideal solution for the beverage industry as the optimum closure for glass bottles with carbonated drinks.

## 1.2 TYPES OF CLOSURES

There is a large number of closure options available today that vary in functional and aesthetic requirements. A closure has three basic functions:

1. Provide containment through positive seal.
2. Provide access and re-sealability according to various requirements of convenience and control.
3. To provide a vehicle for visual, audible, and tactile communication.

In addition to the above three functions, the closure should also protect the content against migration of gases, vapor, and other volatile compounds like organic flavor. The different functions of closures are discussed briefly in this section.

**Positive seal**: A positive seal is attained when the contact points of the closure and the top of the container are pressed together to form a seal. Sometimes a resilient lining material is present which is compressed between the closure and the container, providing a tighter and secure seal. The integrity of the closure with the bottle or the container depends on a number of things like resiliency of the liner, flatness of the sealing surface on the container and above all the tightness or the torque with which it is applied. This application torque should be made accordingly, since too high torque will make it difficult to remove the cap, and at the other extreme, there is the risk of the closure coming off that will result in leakage during the shipment. The only practical way to check the tightness is to measure the removal torque (Hanlon, 1992). The liner could be made of paper, plastic, metal foil, or a composite material. The Friction Fitting closures and the Thread Engagement closures are widely used to provide containment and sealing.

**Convenience and Control**: The demand in the market place and some legal mandates play a very important role in designing these closures. Easy opening, dispensing and critical access control are the critical demands which a closure must satisfy. Easy access and access control are two extremes which are often very difficult to combine and control. For access control two different closures are used by the industry. These are the "tamper evident closures" and the "child resistant closures". Of these closures, 95% are made of plastics and remaining 5% are combinations of metal and plastic.

**Communication**: A closure is the focal point of the container since the consumer has to interact with it to gain access to the contents. It provides a highly visible position for communications, an integral aspect of today's packaging.

Other important things to consider about a closure are the styling aesthetics which promote brand awareness. This might be done with functional embossments, surface textures, company logo, choice of color and surface textures. There can be also graphic symbols like arrows which reflects the importance of safety, convenience and control mechanisms of modern day closures.

Based on the mode of engagement closures can be broadly classified into two sections:

Thread Engagement type

Friction-Fit type

Threaded closures include Continuous thread caps, Lug caps and metal Roll-On type caps. The idea of threaded closures is based on the attachment of a threaded closure to a compatible threaded container neck. The thread design differs in CT (Continuous Thread), Lug type and the Roll-On type in conformance with the finish of the bottle.

Friction Fit type closures include the Snap-fit and Press-on types. The principle here is that the bottles can be sealed with a simple metal or plastic closure which is pressed onto the top and held by friction.

Closures can also classified based on their utility. They are briefly discussed below:

**Containment Closure**: The primary function of the containment closure is a one piece cap providing containment and access on a vast production scale. CT caps, crown caps, roll-on, lug and press-on types are all this type of closures.

**Convenience Closure**: The primary function of convenience closures is to provide easy access to the contents of the container. Closures with consumer convenience features are quite common. Some of the types in this areas are Fixed-Spout closure, Movable-Spout, Plug-Orifice type, Applicators, and Spray pump dispensers. To meet the customer driven market demand newer types of these closures are under research.

**Control Closure**: The need for control closures grew in order to combat with the increasing hygienic problems and increase in the number of such products. Some of the typical control closures used in the market are Tamper Evident (TE) closure, Breakaway caps, Tear bands, Child Resistant closures. These types of closures are increasing in number with more and more legal mandates passed by the US Congress, FDA. and other governing bodies.

**Special Purpose Closure**: These are meant for special applications. They include Aesthetic closure, Special-function closure, Stoppers and Overlaps.

## 1.3 LINING MEDIA

The liner must provide a tight seal, be compatible with the product, and not be a source of contamination. Attention must be given to this part of the closure. Liners are usually made of a resilient backing and a facing material. Sometimes a lubricant is put on the facing. The backing must be soft enough so that it can take care of any irregularities in the sealing surface of the container. It can be either glued to the cap or snapped into a undercut in the cap thereby providing effective seal when the cap is tightened. Facings must also be compatible with the product (Hanlon, 1992). There are numerous types of facing materials. They can be thermoplastic resin coated papers, laminated papers of foil or film or multi-layer custom designed for special applications. Common kinds of inner seals used are waxed pulp, pressure sensitive and heat induction type. The waxed pulp inner seal is common in the food industry. After the filling operation, the container runs under a roller system which applies an adhesive to the lip of the container, while the pulp backing remains in the closure. Pressure sensitive seals are generally foamed polystyrene. The heat-induction kind are plastic laminated to aluminum foils. After the cap is applied, the container passes under an electromagnetic field which causes the aluminum to generate heat. The plastic facing on the aluminum subsequently melts and adheres to the container. The advantage of the inner seal are that it protects form leakers if the cap gets loose, provides a tamper-proof seal and reduces moisture and gas transmission rates.

## 1.4 CLOSURE MATERIALS

The main types of materials used for closures are plastics, metals and glass.

**Plastic**: Molded plastic closures can be divided into two different groups. These are thermoplastic and thermoset closures. Thermoplastics can be softened and recycled by heat while thermoset plastics cannot be recycled once they are molded. Thermoplastics closures can include materials like Low Density Polyethylene, Polypropylene, High Density Polyethylene, and Polystyrene. These types of closures are characterized by relative flexibility, light weight, good chemical resistance and economical resin and manufacturing processes. Thermoplastics closures often provide good application and removal torque. Polypropylene and Polyethylene account for the majority of the thermoplastic closure.

Thermoset closures, on the other hand, are mainly fabricated from Phenolic and Urea compounds. They have a range of chemical compatibility and temperature tolerances and can sustain a wide temperature range from sub zero to as high as 300° F. They have heavy weight and cannot be reprocessed. Thermoset closures can normally be made by compression molding and require a higher cycle time compared to thermoplastics.

**Metal**: Metal caps are generally made of steel, aluminum and sometimes shells which slip over a plastic closures to form composite over-shells. Metal closures are the strongest of all closures and are used for vacuum and pressurized applications. They can be fabricated into continuous thread, vacuum pressure closures, lugs, over-caps and crown caps. The largest market of steel closures is in vacuum packaging.

## 1.5 CLOSURE SELECTION

The main requirements that assist is the selection of the right closure are also described as 5 C's. The 5 C's of closures are containment, convenience, control, communication, and cost.

**Containment**: Essential requirements of containment are product compatibility and the ability to provide functional protection. This objective has to be reached after careful evaluation of the choices available in the terms of methods, types, materials and sealing systems. Decisions may hinge upon whether to use a lining material or linerless closure. Another important variable to be taken note of is the interaction of closure and container system and how they affect efficacy of engagement and seal. Torque considerations also have to account for seal pressure (amount of pressure exerted on the sealing surface) and strip torque (torque at which a closure slips over the container threads).

**Convenience**: This includes the convenient dispensing type closures and can range from simple spouts, plug orifice snap caps, pumps and sprayers. The design of convenience required is determined by the requirements of containment, type of sealing system and the premium placed on convenience.

**Control**: Sometimes it is mandatory to incorporate a control device in the closure. Tamper Evident and Child Resistant closures fall under this category. Cost and sealing needs often determine options in control closures like a secondary sealing or a lining system.

**Communications**: Closures sometimes reflect product quality as it is often the smallest but most prominent part of the package. Closures sometimes communicate both audibly and visually. Steel vacuum button closures "pop" on opening to confirm the freshness of the product and the polypropylene plug orifices "snap" when the seal is engaged.

**Cost**: Last but not the least, this factor dictates closure design and selection. A trade-off is always required between the requirements and the cost factor. Though the thermoplastic molds are costlier than those for thermosets, the faster cycle times and cheaper resins in the former case may prove to be economical in the larger volume runs.

## 1.6 CLOSURE SPECIFICATION

The size and type of thread are designated by the diameter in millimeters coupled with a number which signifies the style, such as deep, shallow or interrupted thread. Therefore a "38-400" designation means that it is 38 mm in diameter and has a shallow continuous thread. The second set of numbers refers to the finish designation. The millimeter designation is used for the only reason that one of the early metal closures were made in France and the system sizes applied to them have continued to the present day (Hanlon, 1992). From the standard table the various dimensions for the 38-400 finish are:

| | | | | |
|---|---|---|---|---|
| T (diameter w/o thread) (min - max) | - | 1.478" | - | 1.484" |
| E (diameter with thread) (min - max) | - | 1.374" | - | 1.380" |
| H (closure height) (max) | - | 0.373" | | |
| P (pitch) | - | 0.1666" | | |
| N (No of turns) (max) | - | 1/32 | | |

The T dimension is the size of the root of the thread inside the closure. E is the inside dimension of the thread in the closure. H is the measurement from the inside top of the closure to the bottom of the closure skirt. A divisional subcommittee of Society of Plastics Industry developed specific finish dimensions, tolerance and thread contours for blow molded plastic bottles. The two basic contours are the M-style and the L-style. M-style thread engaging surfaces are angled at 10° and L-style is angled at 30° which increases the sealing properties of the closures.

## 1.7 SMALL PARCEL ENVIRONMENT

Over the years use of plastic closures have increased since more and more packaged containers are moved from place to place using various forms of transportation. These distribution environments are continuously improved to handle and deliver more packages with increasing efficiencies, in a timely and cost-effective way. Several of these emerging distribution systems form complex network systems which are operated by both federal as well as private companies. These carriers employ various modes of transportation such as trucks, rail air, and water to move packages from one destination to another.

UPS and Federal Express are two major private companies offering door to door shipment of small parcel packages. These companies handle millions of packages everyday. The UPS operates 2250 local service centers while Fed Ex has approximately 1400 such operating centers worldwide. While the concept of picking up and delivering documents and packages is simple, systems that make it operate efficiently and reliably are innovative and expensive. The task of sorting over million packages at one facility, and placing these in containers for return shipments in a few hours, without errors is a continuous challenge.

1.7.1 UNITED PARCEL SERVICE

Today UPS is a major force in the flow of commercial goods, both on the ground and in the air. Its development has spanned much of the modern transportation age beginning earlier this century. The UPS was originally established in 1907 under the name of American Messenger Company. Over the years the company merged and evolved into UPS in 1919. The decades of the 1920's and 1930's were characterized by growth, ingenuity, and change. The company extended operations to Oakland, California, and later to Los Angeles then the fastest growing city in America. In 1929 the company opened United Air Express, offering package delivery via airplane to major west coast cities, and as far inland as El Paso, Texas.

UPS provided delivery services in all major west coast cities, and a foothold was established on the other end of the country with a consolidated delivery service in the New York City area. Many innovations were adopted, including the first mechanical system for package sorting, and a 180-foot-long conveyor belt installed in Los Angeles. The name United Parcel Service was adopted. "United" because shipments were consolidated, and "Service" because, as Charlie Soderstrom observed, "Service is all we have to offer." Trends during the 1940's and 1950's prompted UPS to redefine itself.

By the early 1950's UPS decided to expand their services by acquiring "common carrier" rights to deliver packages between all addresses for both private and commercial customers. This decision placed UPS in direct competition with the

US Postal Service.

While broadening its services, UPS was also expanding in many parts of the country. A package was generally transferred between several carriers before reaching its final destination. This required radical changes in planning and equipment, including a return to delivery by air. In 1953, UPS started offering two-day service to major cities on the East and West coasts. Packages flew in the cargo holds of regularly scheduled airlines "UPS Blue Label Air". The demand for air parcel delivery increased in the 1980's, and federal deregulation of the airline industry created new opportunities for UPS. To ensure dependability, UPS began to assemble its own jet cargo fleet, the largest in the industry. With growing demand for faster service, UPS entered the overnight air delivery business and by 1985, "UPS Next Day Air service" was available in all 48 states and Puerto Rico. Alaska and Hawaii were added later. Same year, UPS entered a new era with international air package and document service, linking the US and six European nations. In 1988 UPS received authorization from the FAA (Federal Aviation Administration) to operate its own aircraft, thus officially becoming an airline. Recruiting the best people available, UPS merged a number of cultures and procedures into a seamless operation called UPS Airline. UPS Airline was the fastest-growing airline in FAA history, formed in little more than one year with all the necessary technology and support systems. Today, UPS Airline is among the ten largest airlines in the US.

UPS Airline features some of the most advanced information systems in the world, like the COMPASS (Computerized Operations Monitoring, Planning and Scheduling System) which provides information for flight planning, scheduling, and load handling. The system, which can be used to plan optimum flight schedules up to six years in advance, is unique in the industry. In the 1980's UPS entered the international shipping market in earnest, establishing a presence in an increasing number of countries and territories in the Americas, Eastern and Western Europe, the Middle East, Africa, and the Pacific Rim. Today, UPS operates an international small package and document network in more than 185 countries and territories, spanning both the Atlantic and Pacific oceans. With its international service, UPS can reach over four billion people, double the number of people who can be reached by any telephone network. By 1993, UPS was delivering 11.5 million packages and documents a day for more than one million regular customers. With such a huge volume, UPS relies on technology to maintain efficiency, to keep prices competitive, and to provide new customer services.

Everyday, customers around the world rely on UPS to ship 11.5 million packages and documents. Whether it's bound for the other side of town, or the other side of the globe, each package passes through the UPS network, which has been carefully engineered to provide speed, reliability, and efficiency. The first step in the process is pick-up. UPS delivery drivers are assigned a specific route, making regularly scheduled stops along the route. Typically, the driver delivers packages in the morning, and picks up packages in the afternoon.

To transport packages efficiently, UPS has developed an elaborate network of "hubs" or central sorting facilities located throughout the world. Each hub is "fed" by a number of local operating centers, which serve as home base for UPS pick-up and delivery vehicles. In one huge but fast-paced operation, the packages are sorted by ZIP code and consolidated on conveyor belts. Packages bound for a specific geographical region are all consolidated on the same conveyor belt. At the other end of the hub, packages undergo a finer sort and are routed to either an out-bound trailer, or for a local delivery, to a package car serving the immediate area. Before being loaded, each package is checked one last time, just to make sure it has been sorted correctly. To transport packages between hubs, UPS uses the ground feeder network. Every day, feeders, or tractor trailers, transport thousands of packages from the hub where the package originated, to the hub nearest to the package's destination. Several types of trailers are used, depending on typical load. They range in size from 24 to 45 feet in length, and carry as many as 1,800 packages. Trailers are specially designed for maximum package security and easy loading/unloading. Their unique features include "roll backs" (rollers that allow packages to be moved more easily from front to back) and "drop frames" (which allow smaller packages to be securely stored at the bottom of the trailer).

Along with shipments moved by ground, UPS handles an average 1.3 million air packages each day, including Next Day and 2nd Day Air packages and documents. To accommodate this volume, UPS uses a system of "air hubs" located around the world. At the main UPS air hub in Louisville, Kentucky, over 60 airplanes land and take off each night. Between 10 p.m. and 2:20 a.m., hundreds of thousands of packages must be unloaded from the aircraft, sorted, then routed to the appropriate ground or air feeder. The UPS fleet consists of Boeing 727, 747, 757, 767, and DC-8 aircraft which fly packages daily to over 390 domestic airports and more than 219 international airports (UPS, 1993).

### 1.7.2 FEDERAL EXPRESS

Federal Express started its business in 1973 from Memphis, TN. Federal Express has grown since then and has specialized mainly in air delivery systems. In 1989, with the acquisition of Tiger International Co. and integration of Flying Tigers Company into its system Federal Express (Fed Ex) became the world's largest full service all cargo international air line. Fed Ex now provides overnight air deliveries to virtually every address in the US through its next day "Priority" and "Standard" service (Federal Express, 1993). The Priority service guarantees delivery of a parcel by 10 a.m. the next working day whereas the standard service ensures that the packages will be delivered by 5 p.m. the next day. Fed Ex handles an average daily package volume of 1.7 million parcels in its combined air delivery services. A total of 465 aircraft are used to make daily connections to 186 countries world wide.

Fed Ex "Priority" services also use the "Hub and Spoke" system to deliver packages. The local operating centers all around the US serve as the "spokes". Each operating center provides pickup and delivery service within an individual territory. The all cargo aircraft connect these local operating centers with the central air hub. The hub is a single sorting center facility. The aircraft called "feeders" take a consignment of packages from local operating centers to the Central air hub for sorting every night. These packages are sorted at the Air-Hub in a matter of approximately three hours. After sorting the packages are loaded into containers, and the aircraft depart with a load of these containers to be delivered the next morning at the destination operating centers.

## 1.8 DISTRIBUTION HAZARDS IN A SMALL PARCEL ENVIRONMENT

During the distribution of packaged goods, damage during handling and sorting is inevitable. There are numerous factors that can cause damage to packaged products during handling and distribution. Once a packaged product is shipped through a small parcel distribution system such as of UPS or Fed Ex, it is subjected to a series of hazards such as drops, impacts, crushing forces, vibration, climatic and pressure changes, before it reaches the customer. These various hazards damage the package and often the products.

Shock is one of the more severe and commonly occurring hazards in small parcel shipping environment. Shock occurs when a moving object comes in contact with a stationary object, either a package or a surface. Shocks often result from packages being dropped, tossed, and sorted. All these occur as packages are handled and sorted manually or by automatic sorting equipment.

On the other hand, a package can also suffer damage in-transit resulting from vibration and compression forces in trucks, rail cars, aircraft, etc. The severity of the damage varies with distance as well as surface of travel.

Most of the previous studies investigated dynamic characteristics of the in-transit environment. Hausch (1975) studied vibration and its interaction with package systems in the transportation environment. The study showed that the truck vibration environment seems to be the most severe at lower frequencies. The aircraft shipping environment had higher acceleration levels at higher frequencies compared to truck and rail. In another study conducted by Marcondes (1988), the dynamics of three different package types were studied in a Less Than Truckload (LTL) shipment. The study showed that accelerations as high as 10 G were encountered during vibration in packages at the top of the stack. Packages with low natural frequency show more bouncing with larger acceleration levels than those with higher natural frequencies.

Voss (1991) measured the dynamics of the small parcel environment in the UPS ground shipping environment. Results showed that the highest drop height measured was 42.1 inches. The size of package did not have any significant effect on the drop heights. Weight did not have any significant effect on the medium and larger size packages. However the small size and lighter packages experienced higher drop heights. This was attributed to more automated handling for the larger and heavier packages for the UPS sorting environment. The smaller and lighter packages are often placed on top of the delivery loads and therefore are subjected to higher drop heights.

Changes in temperature and pressure during ground movements in air shipments may also cause problems to sensitive products. There has been a continuous change in the methods by which small packages are handled and transported over the last decade by companies such as Fed Ex and UPS. The effect of these methods can be different on packages designed for conventional full truck load and LTL shipments. It is important to see how the total package system performs in the small parcel environment.

Currently a large volume of liquid products are shipped in gallon size HDPE bottles using small parcel shipping companies such as Federal Express and United Parcel Service. This study is a continuation of a previous study in which gallon size plastic bottles containing water were subjected to drop and vertical vibration in accordance with the ISTA test procedure. The results from this study showed that the main cause of the leakers in the bottles was attributed to drops with the number of leakers depending on closure opening size and type. Vertical vibration did not cause any leaks in the bottle since all the packages were placed upright when tested (Syal, 1994). However a lot of packages shipped in the small parcel environment may be shipped sideways to better optimize the cube efficiency of containers. There is also the possibility of a package be loaded upside down since labels are only used for scanning purposes during some automated sorts. It is therefore necessary to see the effect of vibration in different orientations and its effect on leakers.

## 2.0 STUDY OBJECTIVES

The purpose of this study was to determine the effect of shipping orientation and closure type on leakers in gallon size plastic bottles when they are shipped in the small parcel environment. The reduction in torque in closures was also measured to evaluate the effect of creep and vibration in plastic bottles. This project was funded by the Consortium of Distribution Packaging.

The objectives of this study were:

- Investigate the effect of vibration on the different orientation of packaged bottles and determine if it causes leakers.
- Compare different types of liners and closures to determine which would produce the least number of leaks during vibration.

# 3.0 EXPERIMENTAL DESIGN

This chapter describes the different types of closures used in this study and the test methods and equipment used in this study.

## 3.1 TYPE OF BOTTLE USED

A gallon size round plastic bottle was used in this study. The gallon size represents the majority of bottle sizes used in small parcel environment as indicated by United Parcel Service. Most of these bottles are either packaged four (2 x 2) per box or six (2 x 3) per box. The type of bottle used for the tests was a 38-400 finish, round gallon size, HDPE, natural, non-fluorinated. The average tare weight of the bottles was 110 ± 3 grams. The bottles were provided by Step Products Inc., Broadway, IL.

## 3.2 CLOSURE TYPES

Three different kinds of closures were used. These were manufactured by Phoenix Closures, Napierville, IL. These were,

1. Sure-Seal (0.035 **SS** 226), a foamed LDPE core with top and bottom layers of 2 mil thick LDPE.

2. Foil-Seal (S 70, **FS**) , a closure lined with induction foil.

3. Pressure Sensitive adhesive lined closure (**PS**).

## 3.3 PACKAGE CONFIGURATION

The bottles were filled with 1 gallon (3.78 liters) of water. The bottles were then closed by three different kinds of closures using the application torque as recommended by the manufacturer. Careful closing techniques were used to prevent the damage to the bottle finish from excessive torque application. After closing with the recommended application torque, six bottles having the same kind of closure type were packed in a regular single wall RSC type corrugated box with a ECT (Edge Crush Test) value of 44 lb/in. with single wall corrugated internal dividers to provide extra support as recommended by the supplier. For each closure type, 10 boxes were prepared. Eight of these boxes were conditioned at 72°F, 50% RH for 72 hours as per ASTM D 4332. The bottles remaining in the two boxes were inspected for immediate removal torque. These two boxes were referred to as "Immediate Removal Torque" (IRT).

After conditioning for 72 hours two of the boxes were randomly selected and the bottles tested for removal torque. These bottles were designated as "Control" and the data collected was used to determine the loss in torque due to creep. The remaining six boxes were tested for vibration. Two boxes were tested in each of the following three orientations:

- Large Side (LxD) Down
- Small Side (WxD) Down
- Top Down (Upside Down)

The bottles were then inspected for any leaks after the vibration test. Any of the bottles that did not show leaks were tested for removal torque. The bottles with the induction seal type caps were re-tightened to account for the fact that there was a loss in the application torque value during the induction sealing process.

A total of 180 bottles and closures were tested in this study.

## 3.4 PACKAGE VIBRATION TEST

The corrugated boxes after being conditioned were subjected to vibration tests. The gross weight of the filled boxes was 54.0 ± 1 lbs. The packages were subjected to a resonance scan from 3.5 - 100 Hz. It was found that the boxes started to resonate at approximately 5.8 Hz. (5.7 - 5.9 Hz). The input acceleration of 1.1 G was applied to the boxes to initiate repetitive bouncing. The duration of the vibration test at the resonant frequency was 45 minutes. After the test all the packages were inspected for leakers and the removal torque. Both the application and removal torques were measured on all the bottles using a Secure Pak Electronic Torque Tester.

## 4.0 CALCULATING THE PERCENT REDUCTION IN TORQUE

The percent reduction in torque was determined for all bottles using the following equation.

$$\%\ Reduction = \frac{T_A - T_R}{T_A}$$

where,

$T_A$-*Application Torque*

$T_R$-*Removal Torque*

The bottles that had leakers from the finish had no removal torque and therefore showed a 100% reduction in torque. The bottles that had leaks in the various sections of the bottle (base or side) were still tested for removal torque.

## 5.0 DATA AND RESULTS

The data for the application and removal torque for individual bottles are presented in Tables through 5. All torque measurements were made in in.-lb. using a Secure Pak Torque Tester.

The leakers observed were categorized into three types:

1. Leak from the bottle base (i.e base crack) designated as LB.
2. Leak from side partition joint (i.e. body crack) designated as LS.
3. Leak from closure finish designated as LC.

The first two categories of leaks are a result of a poor bottle strength where the flexing of the side wall or dynamic compression by the bottles on top caused the bottle to fail resulting in a leak. The third type of leak depends upon the closure/finish interface and the type of liner used.

Table 6 shows the different types of leaks found in the three types of bottle/closure combinations. Both the PS and FS type of liner showed no leak from the finish of the bottle. The SS type of liner had a leak from the finish in two different orientations. The majority of the leaks were observed from the bottle base cracking followed by cracks in the sidewall or body of the bottle. This is attributed to the flexing of the side-wall during vibration and the dynamic compression caused by the bottles on the top.

Table 7 through 11 show the percent reduction measured for all the bottles tested in the different orientations. Table 12 provides the average percent reduction in torque for the different categories and the corresponding standard deviation. This data is also graphically shown in Figure 1. The data shows that there is approximately 30% reduction in torque as a result of immediate removal torque. The effect of creep in 72 hours produced between 45 to 71 percent reduction in torque. Vibration showed reduction between 53 to 78 percent.

The foil seal (FS) type of liner showed the least reduction in torque as compared to the other two types of liners (PS and SS). The data also showed that the SS type of closure had the highest reduction in torque for all conditions tested. The small side orientation in vibration resulted in the most leaks due to the failure of the bottles at the base and side-wall.

TABLE 1 : Application and Removal Torque for 38-400 Round Bottle (Immediate Removal Torque)

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | | | | |
|---|---|---|---|---|---|---|---|
| | | PS | | SS | | FS | |
| | | TORQUE (in-lb) | | TORQUE (in-lb) | | TORQUE (in-lb) | |
| | | APP | REM | APP | REM | APP | REM |
| 1 | 1 | 21.4 | 18.2 | 27.3 | 19.7 | 28.1 | 20.8 |
| | 2 | 28.1 | 17.2 | 28.7 | 18.9 | 29.0 | 20.5 |
| | 3 | 27.4 | 15.4 | 27.4 | 16.0 | 28.4 | 19.6 |
| | 4 | 25.8 | 18.6 | 23.4 | 13.6 | 31.1 | 19.6 |
| | 5 | 23.3 | 19.0 | 27.4 | 17.8 | 28.1 | 20.5 |
| | 6 | 25.9 | 12.4 | 26.5 | 17.7 | 29.5 | 21.0 |
| 2 | 7 | 27.9 | 19.8 | 25.9 | 17.8 | 29.7 | 20.6 |
| | 8 | 29.3 | 17.8 | 28.8 | 17.9 | 28.9 | 21.1 |
| | 9 | 23.6 | 17.9 | 28.7 | 18.2 | 29.4 | 20.8 |
| | 10 | 23.9 | 17.0 | 29.1 | 18.5 | 32.0 | 24.6 |
| | 11 | 25.5 | 14.5 | 25.6 | 18.9 | 30.7 | 23.1 |
| | 12 | 26.8 | 15.7 | 28.5 | 20.7 | 26.0 | 19.7 |

TABLE 2: Application and Removal Torque for 38-400 Round Bottle (Control, Conditioned Standard 72 hrs)

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | | | | |
|---|---|---|---|---|---|---|---|
| | | PS | | SS | | FS | |
| | | TORQUE (in-lb) | | TORQUE (in-lb) | | TORQUE (in-lb) | |
| | | APP | REM | APP | REM | APP | REM |
| 1 | C1 | 27.2 | 12.4 | 28.3 | 8.4 | 27.9 | 17.4 |
| | C2 | 29.5 | 10.0 | 29.4 | 8.5 | 29.3 | 16.5 |
| | M3 | 31.0 | 10.4 | 29.8 | 10.1 | 28.5 | 17.8 |
| | M4 | 27.3 | 9.7 | 28.8 | 8.1 | 28.3 | 16.1 |
| | C5 | 26.2 | 13.5 | 31.1 | 8.7 | 27.8 | 16.5 |
| | C6 | 26.8 | 9.0 | 31.0 | 8.7 | 26.4 | 12.4 |
| 2 | C1 | 26.0 | 8.5 | 38.7 | 8.5 | 27.8 | 16.3 |
| | C2 | 28.8 | 9.3 | 31.8 | 9.4 | 26.5 | 12.3 |
| | M3 | 24.5 | 8.7 | 30.7 | 7.9 | 27.3 | 16.4 |
| | M4 | 25.9 | 8.5 | 28.6 | 8.3 | 28.0 | 12.0 |
| | C5 | 28.4 | 9.6 | 29.7 | 8.4 | 27.6 | 13.0 |
| | C6 | 27.3 | 9.4 | 28.8 | 8.6 | 27.0 | 17.3 |

TABLE 3: Application and Removal Torque for 38-400 Round Bottle (Top Down, Standard 72 hrs)

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | | | | |
|---|---|---|---|---|---|---|---|
| | | PS | | SS | | FS | |
| | | TORQUE (in-lb) | | TORQUE (in-lb) | | TORQUE (in-lb) | |
| | | APP | REM | APP | REM | APP | REM |
| 1 | C1 | 25.9 | 6.9 | 29.4 | 7.4 | 28.7 | 14.5 |
| | C2 | 25.8 | 6.1(L B) | 30.8 | 8.8 | 27.6 | 14.8 |
| | M3 | 25.3 | 4.4(L B) | 29.0 | 6.7 | 29.0 | 14.1 |
| | M4 | 25.5 | 4.5 | 27.3 | 5.6 | 29.3 | 15.9 |
| | C5 | 23.3 | 6.0 | 30.2 | 9.4 | 29.1 | 13.7 |
| | C6 | 25.4 | 11.2 | 28.3 | 0.0(LC) | 30.1 | 13.3 |
| 2 | C1 | 26.1 | 10.3 | 29.9 | 6.7 | 28.3 | 12.4 |
| | C2 | 26.6 | 12.7 | 29.2 | 6.2 | 28.0 | 12.3 |
| | M3 | 24.6 | 9.5 | 29.3 | 6.4 | 29.6 | 16.5 |
| | M4 | 25.6 | 13.5 | 27.2 | 6.7 | 30.5 | 9.6 |
| | C5 | 24.6 | 8.7 | 28.0 | 7.4 | 29.8 | 12.9 |
| | C6 | 25.8 | 11.5 | 27.1 | 5.8 | 31.0 | 13.2 |

TABLE 4: Application and Removal Torque for 38-400 Round Bottle (Small Side Down, Conditioned 72 hrs)

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | | | | |
|---|---|---|---|---|---|---|---|
| | | PS | | SS | | FS | |
| | | TORQUE (in-lb) | | TORQUE (in-lb) | | TORQUE (in-lb) | |
| | | APP | REM | APP | REM | APP | REM |
| 1 | C1 | 28.9 | 9.8 | 27.5 | 9.4 | 27.8 | 11.1 |
| | C2 | 27.5 | 8.1 | 26.9 | 9.0 | 28.8 | 11.9 |
| | M3 | 27.3 | 7.8 | 28.4 | 8.0 | 27.4 | 9.8(L B) |
| | M4 | 27.0 | 8.1 | 27.4 | 9.1 | 29.5 | 12.3 |
| | C5 | 28.4 | 8.6(L B) | 29.5 | 9.1 | 28.1 | 13.0 |
| | C6 | 29.6 | 7.6(L B) | 28.6 | 9.1 | 27.5 | 10.8 |
| 2 | C1 | 27.9 | 8.4 | 28.8 | 8.3 | 28.9 | 9.7(L B) |
| | C2 | 28.6 | 9.0 | 29.6 | 9.4 | 28.4 | 7.7(L B) |
| | M3 | 27.9 | 8.2 | 29.0 | 8.5 | 29.7 | 9.1(L B) |
| | M4 | 28.9 | 7.2 | 29.5 | 8.4 | 27.4 | 8.0(L B) |
| | C5 | 27.0 | 7.4(L S) | 30.1 | 8.7 | 29.2 | 10.1 |
| | C6 | 29.6 | 9.5 | 29.6 | 0.0(LC) | 29.0 | 7.9 |

TABLE 5: Application and Removal Torque for 38-400 Round Bottle (Large Side Down, Standard 72 hrs)

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | | | | |
|---|---|---|---|---|---|---|---|
| | | PS | | SS | | FS | |
| | | TORQUE (in-lb) | | TORQUE (in-lb) | | TORQUE (in-lb) | |
| | | APP | REM | APP | REM | APP | REM |
| 1 | C1 | 26.3 | 10.0 | 26.0 | 11.0 | 28.8 | 10.5(L B) |
| | C2 | 24.7 | 9.8 | 29.3 | 9.7 | 30.3 | 15.6 |
| | M3 | 25.0 | 10.2 | 30.0 | 9.2 | 27.5 | 12.1 |
| | M4 | 27.0 | 10.4 | 30.2 | 7.9 | 27.6 | 13.3 |
| | C5 | 27.2 | 10.3 | 28.2 | 8.0 | 29.8 | 9.3 |
| | C6 | 24.3 | 9.9 | 28.2 | 7.6 | 27.1 | 15.7 |
| 2 | C1 | 26.5 | 10.1 | 27.1 | 10.7 | 29.8 | 9.5 |
| | C2 | 24.5 | 10.4 | 28.0 | 8.5(L B) | 30.5 | 11.8 |
| | M3 | 27.9 | 9.9 | 29.3 | 8.3 | 29.4 | 12.7 |
| | M4 | 27.7 | 8.9 | 29.4 | 7.8 | 28.1 | 9.9 |
| | C5 | 28.7 | 10.6 | 28.6 | 8.4(L B) | 27.5 | 11.6 |
| | C6 | 25.2 | 8.8(L B) | 28.8 | 9.9 | 28.8 | 11.2 |

TABLE 6: Number of Bottles With Leaks after Vibration Testing.

| Conditions | Nature of Leaks observed | No. of bottles leaking | | |
|---|---|---|---|---|
| | | Closure Types | | |
| | | PS | SS | FS |
| Vibration Tested Top Down, Conditioned Standard 72 hrs | Leak from finish | **0** | **1** | **0** |
| | Leak from base crack | 0 | 0 | 0 |
| | Leak from body crack | 2 | 0 | 0 |
| Vibration Tested Small Side Down Conditioned Standard 72 hrs | Leak from finish | **0** | **1** | **0** |
| | Leak from base crack | 2 | 0 | 5 |
| | Leak from body crack | 1 | 0 | 0 |
| Vibration Tested Large Side Down Conditioned Standard 72 hrs | Leak from finish | **0** | **0** | **0** |
| | Leak from base crack | 1 | 2 | 1 |
| | Leak from body crack | 0 | 0 | 0 |

TABLE 7: Percent Reduction of Torque in 38-400 Round Gallon Bottles Immediate Removal Torque

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| | | %Reduction | %Reduction | %Reduction |
| 1 | 1 | 15.0 | 27.8 | 26.0 |
| | 2 | 38.8 | 34.1 | 29.3 |
| | 3 | 43.8 | 41.6 | 31.0 |
| | 4 | 27.9 | 41.9 | 37.0 |
| | 5 | 18.5 | 35.0 | 27.0 |
| | 6 | 52.1 | 33.2 | 28.8 |
| 2 | 7 | 29.0 | 31.3 | 30.6 |
| | 8 | 39.2 | 37.8 | 27.0 |
| | 9 | 24.2 | 36.6 | 29.3 |
| | 10 | 28.9 | 36.4 | 23.1 |
| | 11 | 43.1 | 26.2 | 24.8 |
| | 12 | 41.4 | 27.4 | 24.8 |
| **Average** | | **33.5** | **34.1** | **28.2** |
| **Standard deviation** | | **11.3** | **5.2** | **3.7** |

TABLE 8: Percent Reduction of Torque in 38-400 Round Gallon Bottles Control, Conditioned Standard for 72 Hours

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| | | %Reduction | %Reduction | %Reduction |
| 1 | C1 | 54.4 | 70.3 | 37.6 |
| | C2 | 66.1 | 71.1 | 43.7 |
| | M3 | 66.5 | 66.1 | 37.5 |
| | M4 | 64.5 | 71.9 | 43.1 |
| | C5 | 48.5 | 72.0 | 40.6 |
| | C6 | 66.4 | 71.9 | 53.0 |
| 2 | C1 | 67.3 | 70.4 | 41.4 |
| | C2 | 67.7 | 70.4 | 53.6 |
| | M3 | 64.5 | 74.3 | 39.9 |
| | M4 | 67.2 | 71.0 | 57.1 |
| | C5 | 66.2 | 71.7 | 52.9 |
| | C6 | 65.6 | 70.1 | 35.9 |
| **Average** | | **63.7** | **70.9** | **44.7** |
| **Standard deviation** | | **6.0** | **1.9** | **7.4** |

TABLE 9: Percent Reduction of Torque in 38-400 Round Gallon Bottles Top Down vibration Tested, Conditioned Standard 72 hrs

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| | | %Reduction | %Reduction | %Reduction |
| 1 | C1 | 73.4 | 74.8 | 49.5 |
| | C2 | 76.4 | 71.4 | 46.4 |
| | M3 | 82.6 | 76.9 | 51.4 |
| | M4 | 82.4 | 79.5 | 45.7 |
| | C5 | 74.2 | 68.9 | 52.9 |
| | C6 | 55.9 | 100.0 | 55.8 |
| 2 | C1 | 60.5 | 77.6 | 56.2 |
| | C2 | 52.3 | 78.8 | 56.1 |
| | M3 | 61.4 | 78.2 | 44.3 |
| | M4 | 47.3 | 75.4 | 68.5 |
| | C5 | 64.6 | 73.6 | 56.7 |
| | C6 | 55.4 | 78.6 | 57.4 |
| **Average** | | **65.5** | **77.8** | **53.4** |
| **Standard deviation** | | **12.0** | **7.7** | **6.7** |

TABLE 10: Percent Reduction of Torque in 38-400 Round Gallon Bottles Small Side Down vibration Tested, Conditioned Standard 72 hrs

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| | | %Reduction | %Reduction | %Reduction |
| 1 | C1 | 66.1 | 65.8 | 60.1 |
| | C2 | 70.5 | 66.5 | 58.7 |
| | M3 | 71.4 | 71.8 | 64.2 |
| | M4 | 70.0 | 66.8 | 58.3 |
| | C5 | 69.7 | 69.2 | 53.7 |
| | C6 | 74.3 | 68.2 | 60.7 |
| 2 | C1 | 69.9 | 71.2 | 66.4 |
| | C2 | 68.5 | 68.2 | 72.9 |
| | M3 | 70.6 | 70.7 | 69.4 |
| | M4 | 75.1 | 71.5 | 70.8 |
| | C5 | 72.6 | 71.1 | 65.4 |
| | C6 | 67.9 | 100.0 | 72.8 |
| **Average** | | **70.6** | **71.8** | **64.5** |
| **Standard deviation** | | **2.6** | **9.1** | **6.2** |

TABLE 11: Percent Reduction of Torque in 38-400 Round Gallon Bottles Large Side Down vibration Tested, Conditioned Standard 72 hrs

| PACKAGE SAMPLE | BOTTLE NUMBER AND LOCATION | CLOSURE TYPE | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| | | %Reduction | %Reduction | %Reduction |
| 1 | C1 | 62.0 | 57.7 | 63.5 |
| | C2 | 60.3 | 66.9 | 48.5 |
| | M3 | 59.2 | 69.3 | 56.0 |
| | M4 | 61.5 | 73.8 | 51.8 |
| | C5 | 62.1 | 71.6 | 68.8 |
| | C6 | 59.3 | 73.0 | 42.1 |
| 2 | C1 | 61.9 | 60.5 | 68.1 |
| | C2 | 57.6 | 69.6 | 61.3 |
| | M3 | 64.5 | 71.7 | 56.8 |
| | M4 | 67.9 | 73.5 | 64.8 |
| | C5 | 63.1 | 70.6 | 57.8 |
| | C6 | 65.1 | 65.6 | 61.1 |
| **Average** | | **62.0** | **68.7** | **58.4** |
| **Standard deviation** | | **2.9** | **5.1** | **8.0** |

TABLE 12: Average and Standard Deviation of Percent Reduction Torque after Conditioning and Testing.

| Condition | Average & Standard Deviation | Closure System | | |
|---|---|---|---|---|
| | | PS | SS | FS |
| Immediate Removal Torque | Avg. | 33.5 | 34.1 | 28.2 |
| | Std.Dev. | 11.3 | 5.2 | 3.7 |
| Control, Conditioned Standard 72 hrs. | Avg. | 63.7 | 70.9 | 44.7 |
| | Std.Dev. | 6.0 | 1.9 | 7.4 |
| Vibration Tested Top Down, Conditioned Standard | Avg. | 65.5 | 77.8 | 53.4 |
| | Std.Dev. | 12.0 | 7.7 | 6.7 |
| Vibration Tested Small Side Down, Conditioned Standard | Avg. | 70.6 | 71.8 | 64.5 |
| | Std.Dev. | 2.6 | 9.1 | 6.2 |
| Vibration Tested Large Side Down, Conditioned Standard | Avg. | 62.0 | 68.7 | 58.4 |
| | Std.Dev. | 2.9 | 5.1 | 8.0 |

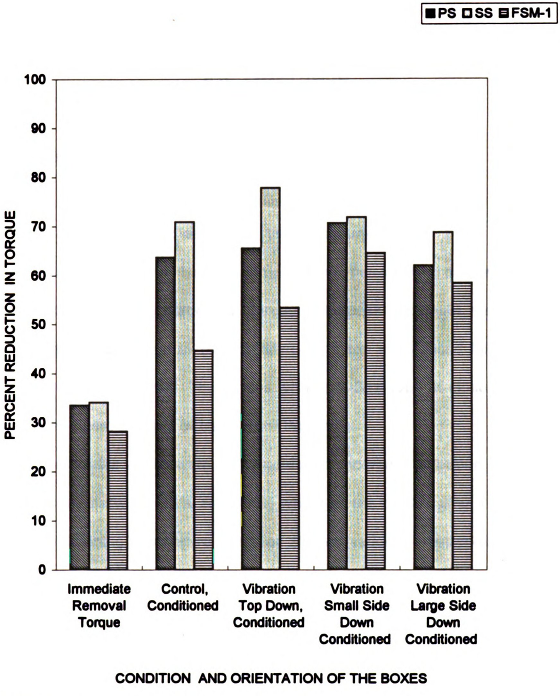


FIGURE 1: Average Percent Reduction in Torque

## 6.0 CONCLUSION

The following conclusions were made:

1. The most leaks in all bottles tested occurred in the bottle base and sidewall due to the dynamic compression when vibrated on the side. The "small side" orientation in vibration produces maximum force on the bottom bottle due to two bottles on the top and caused failure in the base and side-wall. The bottles with Sure-Seal type of closure showed the largest number of leaks from the finish.
2. The bottles which were not conditioned showed a reduction in removal torque between 28% and 34%, where as the bottles after 72 hours of conditioning at standard condition showed reduction between 45% and 71%. The bottles which were tested for vibration after conditioning at standard condition for 72 hours showed torque reduction between 53% and 78%.

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## LIST OF REFERENCES

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