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thesis entitled

PANELING OF PLASTIC BOTTLES

presented by

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has been accepted towards fulfillment
of the requirements for

Masters degree in Packaging

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Date April 12, 2002

PANELING OF PLASTIC BOTTLES

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

School of Packaging

2002

ABSTRACT

PANELING OF PLASTIC BOTTLES

By

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Paneling of plastic bottles has been observed in several packaged products. Until now, the fundamentals involved in causing the paneling of plastic bottles have not been clearly understood. There are presently no general methodologies to resolve paneling problems. Pressure differential has been identified as a possible cause of paneling. Causes of pressure differential have not been experimentally verified.

This study demonstrated experimentally that one possible cause of paneling may be removal of oxygen from the headspace, leading to a pressure differential. Such factors as wall thickness variation and creep, probably influenced the occurrence of paneling. A question guide is suggested for analyzing paneling in order to find solutions to paneling problems.

DEDICATION

This thesis is dedicated to my wife, Dr. Geetha Bhai Pillai and my two sons, Diivanand and Deeban, who gave me all the encouragement and support I needed to complete my thesis and degree.

ACKNOWLEDGEMENTS

I thank Dr. Hugh Lockhart for the guidance, patience and understanding shown to me during the writing of my thesis and in making my thesis a success. I would also like to thank Dr. Susan Selke, Dr. Gary Burgess and Dr. K.Jayaraman for their guidance and support. My hearty thanks to Mr. Robert Hurwitz for helping in setting up the experiment,and Mr. Supoj Pratheepthinthong for helping me to take photographs of my experiment.

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KEY TO SYMBOLS OR ABBREVIATIONS:

PET : Polyethylene terephthalate
PVC : Polyvinyl chloride
HDPE: High-density polyethylene
OD : Outside diameter
ml : Milliliter
mmHg: Millimeters of mercury
inHg: Inches of mercury
K : Kelvin
F : Fahrenheit
% : Percentage
" : Inches
fl : Flow
Oz : Ounze

INTRODUCTION

Paneling is the term used to describe the action of a plastic bottle when it forms a concavity somewhere in the body. There may be one concavity or more than one. Figure 1 shows an undeformed bottle and Figure 2 shows a paneled bottle. These bottles have been used for differentiating deformed from undeformed bottle, and have not been used in any experiments in this thesis. The body of the bottle is the section of the bottle between the shoulder and the heel. This section can be cylindrical, square, rectangular or oval in cross section.

The paneling of plastic bottles has been observed in a variety of packaged products. Examples of these products are nutritional/dietary supplements, hot-filled products, agricultural chemical products, sanitizers and hair care products. The magnitude of paneling has been observed from a size of 1 inch in length, 1/2 inch in width and a 1/8 inch in depth, to a larger area of 3 inches in length, 1 1/2 inches in width and 3/4 inch in depth. These examples of paneled bottles have been observed during outgoing inspection, upon breakdown of shipping units when stocking shelves and on the shelves of various retail outlets.

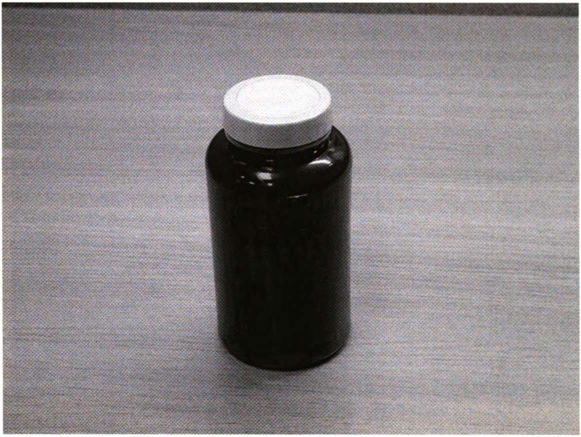

Figure 1. Undeformed Bottle

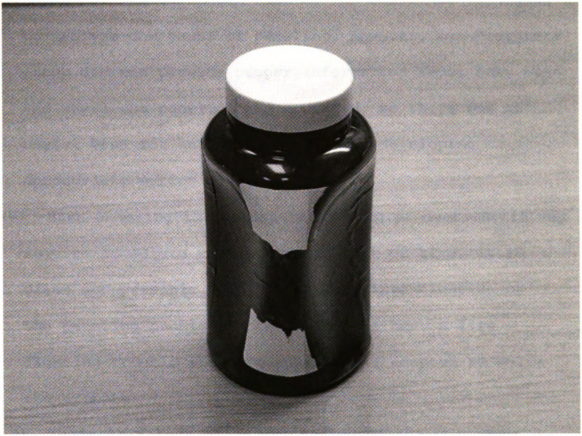

Figure 2. Paneled Bottle

Study of the paneling of plastic bottles is useful for the following reasons:

(a) There are many requests from manufacturers to provide solution to overcome paneling of plastic bottles. Some of these samples have been sent to the School of Packaging to analyze the cause of paneling. However, manufacturers often did not provide proper information about how, when and where the paneling had occurred, so there was no useful base for analyzing causes and developing appropriate action plans.

(b) When paneling is encountered during production, it may require immediate remedy. Due to lack of time, it is often not possible to do a detailed investigation of the paneling problem at that time. Rather, a fire fighting trouble shooting approach is adopted to solve the problem.

(c) There is a lack of understanding of the phenomena that cause paneling. An in-depth understanding of the causes of paneling will enable an appropriate resolution of paneling problems.

(d) There is a lack of methodology to analyze and resolve paneling questions. An appropriate analytical or practical technique will facilitate a systematic problem solving process. The technique should cover all processes involved from the moment the product is filled, until the package reaches the retail shelves.

The goals of this project were:

(a) To gain knowledge for resolving paneling questions.

(b) To gain knowledge on how to design bottles that will not panel. The design will include the size, shape, thickness distribution and all dimensions.

(c) To develop a test:

   (i) for evaluating the resistance of bottles to paneling.

   (ii) for incoming quality control, to ensure that the bottles will not panel after filling until they are sold.

CHAPTER 1

LITERATURE REVIEW

Jones et al., (1963), described possible causes of paneling of high density polyethylene bottles as the following:

(a) The loss of product contained in the bottle leaves a vacuum, which draws in the bottle walls. This loss results initially from absorption of the product into the container walls. The continued absorption causes the product to diffuse through the walls, and it finally evaporates to the outside. This leads to an increase in the headspace volume. Since the bottle is tightly capped to prevent product leakage and air passage from the outside to the inside of the bottle, underpressure develops in the headspace. Factors that influence paneling are solubility and permeability, which depend on resin density. Resin with lower density results in higher solubility and permeability.

(b) If the containers are filled and capped when the product is above room temperature, a partial vacuum will develop upon cooling of the contents due to a reduction in the volume of the product. Likewise, if the container is capped while the head space is full of foam, a vacuum will develop on condensation of the foam.

No experimental verification of these causes of paneling was presented.

According to Jones et al., (1961), paneling is affected by the shape of the bottle. For example a comparative storage test for 30 days at 140°F with motor oil in a four ounce Boston Round bottle and a four ounce Flat Oval bottle, showed that the four ounce Boston Round bottle had significant wall collapse, whereas the four ounce Flat Oval bottle had very slight wall collapse.

Rosato D.V. et al., (1989), described possible causes of paneling of high density polyethylene bottles as the following:

a) Permeation - The contents or components of the contents may permeate sufficiently to create a partial vacuum in the container.

b) Swelling - The chemical contents of the container may cause swelling of the surface of the wall of the bottle.

c) Gas solution - Certain materials will absorb gases, usually oxygen, from the headspace of the sealed container and create a partial vacuum. It was not clearly explained whether the "certain material" referred to product or the package.

d) Oxidation - Some materials oxidize easily, thus removing the oxygen from the headspace and creating a partial vacuum. Unpigmented polyethylene will not protect against ultra-violet light which acts as an oxidative catalyst on some products to remove oxygen from the headspace to creating a partial vacuum.

e) Hot fill - Filling and sealing of contents at significantly elevated temperature, may result in contraction on cooling, to form a partial vacuum.

Again, there was no experimental verification of the causes of paneling.

Dimitri Tsiourvas et al., (1993), has highlighted that the pressure difference between the inside and the outside of the container can be created by:

(a) the difference between the filling and storage temperatures.

(b) the absorption of air contained in the headspace by the bottle contents.

(c) the creation of gas owing to chemical or biological processes during storage. (This should not be a factor in paneling, since the creation of gas would increase the internal pressure and lead to bulging of the body of the bottle, not paneling).

The author's experimental work was confined to three layer coextruded bottles (polyamide 6/bonding layer/high density polyethylene). He subjected four different bottle designs to vacuum testing and evaluated their resistance to deformation.

Van Dijk et al., (1998) highlighted that an underpressure can occur due to one or more of the following factors:

(a) Altitude differences (eg. filling at high altitude followed by transportation to lower altitudes).

(b) Temperature differences (filling at higher than ambient temperature will result in contraction of the volume in the bottle and reduction of the headspace pressure).

(c) Chemical (e.g. oxidation) or physical (solubility) interactions between the contents and the air in the headspace of the bottle; in due time, these factors can cause under pressure to initiate paneling.

The author's experimental work was confined to advanced design approaches such as Finite Element Analysis which was used to evaluate two different designs of lightweight plastic bottles, a round PET bottle (750 ml) and a square PVC bottle (1000 ml). The two designs were tested for their performance in top load, vacuum and impact resistance. No evidence was presented to prove that the pressure difference is the cause of paneling of plastic bottles.

Table 1 shows a summary of suggested causes of paneling. Vacuum or pressure differences can be created by loss of product, gas solution, removal of oxygen in the headspace, differences in temperature, or some combination of these. Vacuum and pressure differences are obviously interrelated.

Continental PET Technologies Inc., (1989), claims in its patent that paneling is affected by the design of the body of the bottle for a blow molded container which is formed of a polyester resin. The bottle may be hot filled with a liquid at a temperature in the order of 180°F-185°F, and the bottle has a maximum volumetric shrinkage of no greater than 1%. This has been discussed in U.S. patent number 4.863.046 (1989) by Continental PET Technologies Inc., and U.S. patent number 4.877.141 (1989) by Yoshino Kogyosho Co. Ltd. A pressure resistant bottle-shaped container has a body, which has panels surrounded by outer sheaths. Each panel has stress absorbing strips comprised of vertexes, recessed from the outer surface of the panel towards the interior of the container. It has bending lines formed in V-shape and inverted V-shape from the vertexes, towards the outer sheaths. Thus the container does not retain permanent deformation, by the deformation resulting from pressure changes at the time of filling the high temperature liquid content.

Table 1. Condensed version of the possible causes of paneling of plastic bottles

Causes:	Jones D.A. et al, 1961	Rosato D.V. et al, 1989	Dimitri T. et al, 1993	Van Dijk R. et al, 1998
Vacuum/pressure difference due to loss of product	X	X		
Vacuum/pressure difference due to removal of O_2 in headspace		X	X	X
Vacuum/pressure difference due to difference in temperature (hot fill/storage)	X	X	X	X
Pressure difference due to difference in altitude				X
Resin density (solubility/permeability)	X			
Vacuum due to condensation of foam	X			

CHAPTER 2

Field Study of Paneling

In order to evaluate and confirm the possible causes of paneling, an appropriate experiment is required. With literature review alone, it was not possible to set up an experiment. Therefore, a field study of packages that had paneled were studied. Six packages were investigated that were identified as having serious paneling problems.

They were:

(a) 4 Liter hot filled ketchup HDPE bottle

(b) 1 Liter and 2 Liter floor cleaner HDPE bottles

(c) 32 Ounce cleaning product HDPE bottle

(d) 24 Ounce hot filled chocolate syrup HDPE bottle

(e) 1 Liter hair root lifter HDPE bottle

(f) HDPE bottle containing 240 dietary supplement tablets

A field study was carried out by using the "Question Guide for Analyzing the Causes of Paneling" shown in **Appendix A** for each of these packages.

(a) 4 Liter Hot Filled Ketchup HDPE Bottle:

The paneling was observed at food service outlets a week after filling. The middle part of the body paneled. The extent of paneling was about 1.18 inches in length, 1.18 inches in width and 0.39 inch in depth. The thickness of the body wall where the bottle had paneled was about 0.0394 inch.

Underpressure inside the bottle might have been caused by an increase in the volume of headspace, due to shrinkage of volume in the product upon cooling, since the product was filled at 185° F and cooled to a storage temperature between 77° F and 113° F.

Underpressure might also have resulted from condensation of water vapor in the headspace, as the temperature and hence the saturation vapor pressure, decreased. The tight closure prevented leakage of the product, and the passage of air from outside to the inside of the bottle. The high temperature might also have reduced the stiffness of the polyethylene. (Refer to **Appendix B** for further details on the 4 Liter hot filled ketchup HDPE bottle).

(b) 1 Liter & 2 Liter floor cleaner HDPE bottles:

The paneling was observed a day after filling at the factory warehouse during the outgoing inspection. Both front and back label panels had deformed. The extent of paneling was about 0.78 inch in length, 1.18 inches in width and 0.39 inch in depth. The thickness of the bottle wall where it had paneled was about 0.022 inch for the 1 liter bottle, and 0.031 inch for the 2 liter bottle.

According to the manufacturer, there was a possibility of increase in the headspace volume which was thought to be due to condensation of foam and the permeation out of the bottle of product or components of product. Since the cap had to be tightly closed to prevent the leakage of product and the passage of air from outside to the inside of the bottle, should have developed in the headspace.

(Refer to **Appendix C** for further details on the 1 Liter and 2 liter floor cleaner HDPE bottles).

(c) 32 ounce cleaning product HDPE bottle:

Paneling was observed 1-2 weeks after filling. The extent of paneling was about 3 inches in length and 2 inches in width. The thickness of the body wall where the bottle had paneled was about 0.030 inch. Since the products contained solvents and high fragrance, there was a high possibility that product loss could have occurred due to the permeation of these components. Initially, these components would be absorbed into the walls.

They would then diffuse through the wall, and finally evaporate from the outside surface. This would lead to an increase in the headspace volume. Since the liner was tightly sealed to prevent product leakage and air passage from outside to the inside of the bottle, underpressure could develop in the headspace. According to the manufacturer, there was no oxidation since the product would not react with oxygen in the headspace. The temperature difference between the filling and storage was about 8°F but this would not be significant in causing underpressure in the headspace. There was progressive (gradual increase in depth and extent) paneling and a permanent distortion.

(Refer to **Appendix D** for further details on the 32 Ounce cleaning product HDPE bottle).

(d) 24 ounce hot filled chocolate syrup HDPE bottle:

The paneling was observed immediately after filling. The thickness of the body wall where the bottle had paneled was 0.030 inch. According to the manufacturer, there was 3% product volume shrinkage upon cooling. This increased the headspace volume since the product was filled at 185°F and cooled to a storage temperature of 60°F. By using the **ideal gas law,**

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

a theoretical final pressure (P_2) in the headspace can be determined.

Overflow volume of the bottle = 20 fl.oz.

Therefore, headspace volume (V_1) = 1.54 fl.oz

Volume of product with product density of 1.3
= 18.46 fl.oz.

Product shrunk by 3% and this was equal to 0.55 fl.oz.

Therefore new headspace (V_2) = 1.54 + 0.55 = 2.09 fl.oz.

Initial and final volume of the air originally in the headspace would remain the same if the container was rigid and product volume did not change. The pressure in the headspace would be reduced.

Product shrinkage of 3% upon cooling does increase the headspace by 0.55 fl.oz. If the container was rigid, the pressure would be further reduced.

Initial temperature (T_1) = 273 + 185 = 458 K.
Final temperature (T_2) = 273 + 60 = 333 K.

Assuming a hypothetical rigid container, the final pressure (P_2) inside the container would be:

$$P_2 = \frac{P_1 \times V_1 \times T_2}{T_1 \times V_2}$$

$$= \frac{760 \times 1.54 \times 333}{458 \times 2.09}$$

$$= 414.4 \text{ mmHg}$$

This would create a pressure differential of 346 mmHg.

According to the manufacturer, the paneling occurred immediately with cooling of the product to 60°F and remained fixed. The paneling observed is presumed to be the response of the semirigid container as the system tends toward pressure equilibrium.

It has been suggested that an additional factor contributing to pressure differential would be condensation of water vapor in the headspace. However, this contribution is probably negligible.

(Refer to **Appendix E** for further details on the 24 ounce hot filled chocolate syrup HDPE bottle).

(e) 1 liter hair root Lifter HDPE bottles:

The paneling was observed immediately after filling. The thickness of the body wall where the bottle had paneled was 0.018 inch. According to the manufacturer, there was a possibility that the product reacted with oxygen in the headspace, leading to underpressure in the headspace. There was progressive paneling and permanent distortion.

(Refer to **Appendix F** for further details on the 1 liter hair root lifter HDPE bottles).

(f) Dietary supplements:

The paneling was observed 15-20 days after filling. The thickness of the body wall where the body had paneled was 0.0296 inch. The product reacted with oxygen in the headspace (This was confirmed by the manufacturer's own analysis). This led to vacuum and underpressure in the headspace. Since the liner was tightly sealed to prevent the passage of air from outside to the inside of the

bottle, underpressure developed in the headspace.
There was progressive paneling and permanent distortion.
(Refer to **Appendix G** for further details on the dietary supplements).

Summary of field study:

The analysis of the field study on the above six products showed that there was a possibility of development of underpressure in the headspace. The possible causes of underpressure were loss of product due to permeation out of the bottle by product or components of the product, leading to an increase in the volume in the headspace; reaction of the product with the oxygen in the headspace, leading to the removal of oxygen from the headspace; and the contraction of hot filled products upon cooling, leading to an increase in volume of the headspace in the bottle.

The pressure differential was assumed to have caused immediate paneling (about 1-2 minutes, before packing into the shipper, after filling) as in the case of hot filled chocolate syrup and hair root lifter or delayed paneling (1-20 days) as in the case of hot filled ketchup, cleaning products, floor cleaner and dietary supplements. Paneling was observed to be a permanent distortion in all six products.

After this field study, there was still a lack of information about the causes of paneling. Therefore, an experiment was designed to gather more information about paneling. The experiment was carried out by evacuating air from the headspace of bottles at room temperature and observing the vacuum level required to deform the bottle.

The bottles used in the experiment were of the same kind as those in the field study that contained dietary supplement, shampoo, and hair care product.

The experiment was designed to verify,

(a) whether pressure differential could be the cause of paneling;

(b) whether creep was influencing the paneling (Creep is the time dependent increase in strain of a viscous or visco-elastic material under sustained stress); and

(c) whether the thickness variation in the bottle wall was influencing the paneling.

CHAPTER 3

Materials and Method

Introduction:-

A pressure differential was created between the inside and the outside of the bottle by evacuating air from the headspace inside the bottle. The objectives of this experiment were to evaluate

(1) the vacuum level (and so the pressure differential) required to deform the bottle;

(2) the influence of creep on paneling;

(3) the influence of thickness variation on paneling.

Materials:

1. Bottle samples

(a) Dietary Supplements:

White HDPE cylindrical bottle with diameter 2 3/4 inches and height 5 3/8 inches was used for containing dietary supplement tablets.

(b) Shampoo:

White HDPE cylindrical bottle with diameter 1 1/2 inches and height 9 inches used for containing shampoo.

(c) Hair-care products:

Silk screen printed clear HDPE cylindrical bottle with diameter 3 1/4 inches and height 9 5/8 inches used for containing hair-care product.

2. Vacuum pump (Cenco Hyrac 2)

3. Magna Mike (Model 8000; Hall effect thickness gauge; sensitivity = +/- 0.00005 inch)
4. Vacuum gauge (GATT: 0-760 mmHg/0-30 inHg; sensitivity = +/- 5 mmHg / +/- 0.25 inHg)
5. Needle valve (to control and maintain vacuum)
6. Water (used as product simulant for shampoo/hair care product bottles)
7. Dietary supplement tablets (used for testing dietary supplement bottles)
8. Suction flask (Kimax 1000 milliliter with side arm)
9. Vertical stand (metal)
10. Stop watch (Meylan 0-30 minutes; 1/100 of a minute)
11. Flexible connecting tubes (Tygon clear laboratory, R3503 with OD: 3/8; Rubber, thick wall with OD: 5/8)
12. Rigid tube (Nalgene 689 Polypropylene with OD 1/4 inch)
13. Connector kit (straight polypropylene with OD: 3/8 inch)
14. Rubber stoppers (solid Neoprene for closing sample bottles / suction flask)
15. Measuring rulers (6 inches / 12 inches in length)
16. Permanent marker pen
17. Rubber band

Method:

1. The testing was done by filling the bottle with water to the fill level or by using the tablets in the dietary

supplement bottle, and subjecting it to vacuum. The setup of the experiment is shown in **Figure 3.**

2. The sample bottle was first analyzed for variation in thickness. A total of 16 points were measured on the body of the bottle. This was done by making a reference to direction and distance as described in **Figure 4**. The directions, upper, right side, lower and left side were determined clockwise by holding the bottle with the plastic identification symbol facing upright and on the right hand side. The distance of each point from the bottom was measured from the heel.

3. The sample bottle was filled with water and the overflow volume was recorded. The bottle was then emptied. For shampoo and hair care products, the bottle was refilled with water up to a volume of 90% of the overflow volume. In the case of the dietary supplement products, 240 dietary supplement tablets were filled into the bottle. The bottle was closed with a rubber stopper into which was inserted a rigid tube as shown in **Figure 5.**

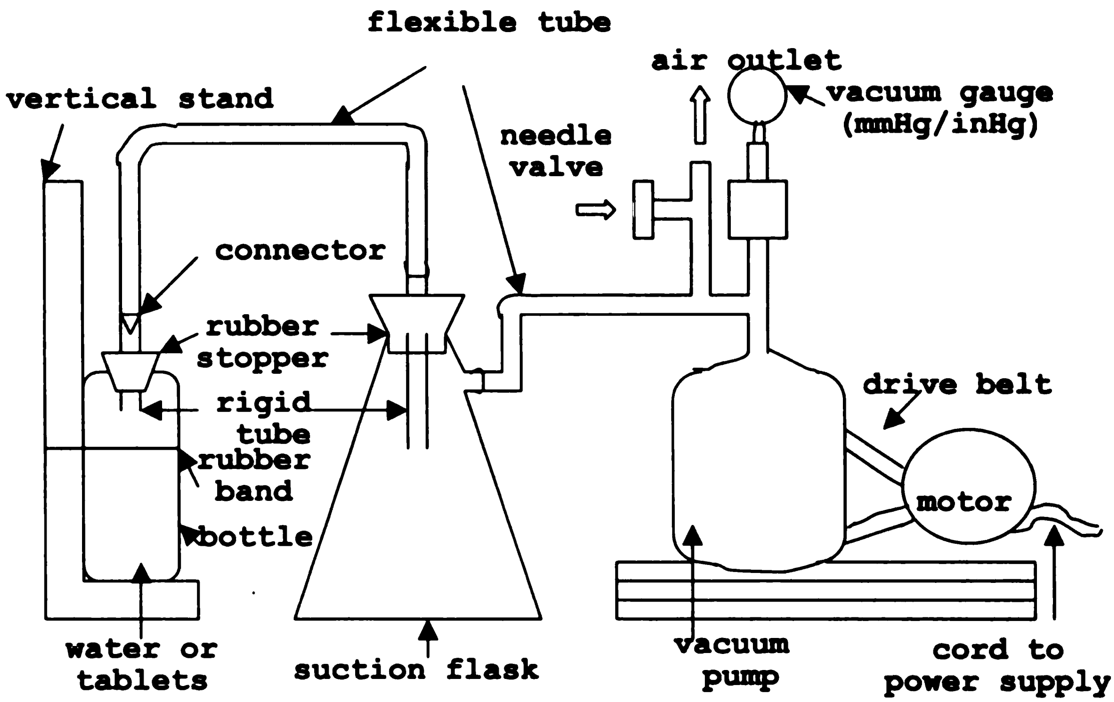

Figure 3. Experiment - Vacuum Testing

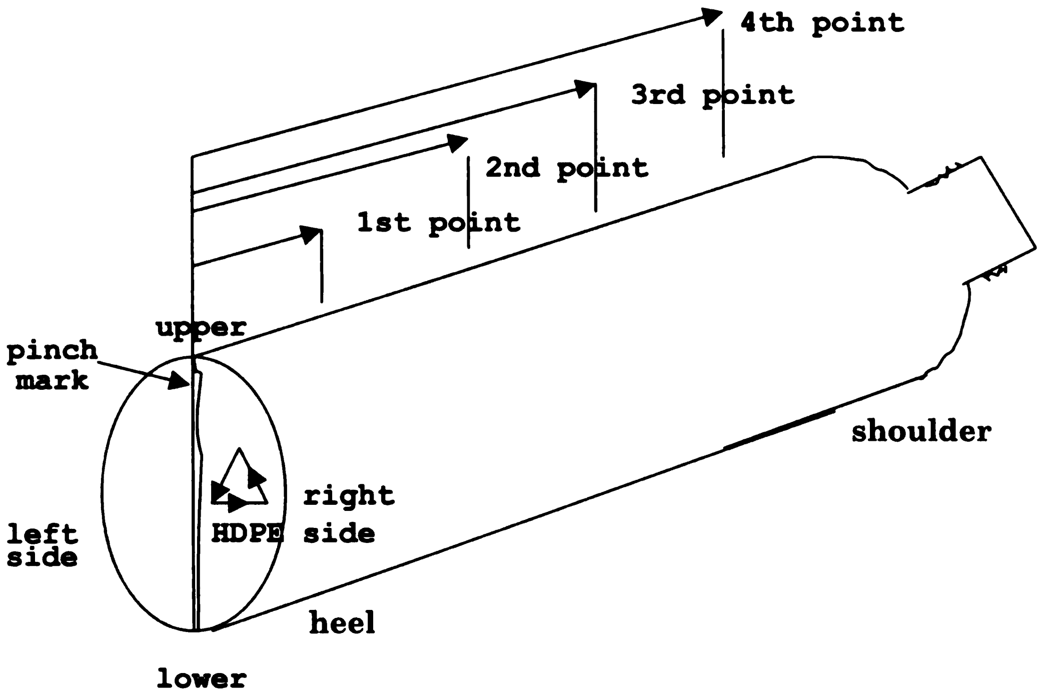

Figure 4. Measurement of the thickness of a point on the body of the bottle

Figure 5. Test sample bottles

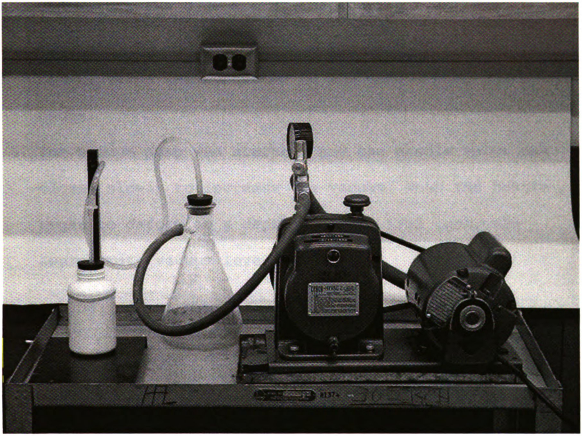

Figure 6. Experiment - dietary supplement bottle

4. The sample bottle was secured to a vertical stand by using a rubber band as shown in **Figure 6.** The sample bottle was connected to the suction flask by a flexible tube, which in turn is connected to a rigid tube by a connector. The side arm of the suction flask was connected to one end of the T-junction needle valve. The needle valve was connected to the vacuum pump and vacuum gauge.
5. The vacuum pump was started, and the needle valve was closed slowly to increase the vacuum. When the bottle began to deform to a depth of about 1/32 inch, the approximate vacuum level was noted.

6. On the same bottle, the immediate paneling was found by setting the vacuum level at intervals of 5 mmHg, starting below 5-10 mmHg of the approximate vacuum level at which the body wall first deformed. The 5 mmHg increment was chosen because the gauge was graduated at intervals of 10 mmHg. Therefore, a sensitivity of 5 mmHg could be used. The vacuum was held for two minutes at each 5 mmHg increment. Immediate paneling is defined as the vacuum level required to deform the body of the bottle to a depth of 1/32 of an inch within 2 minutes. This is shown in **Figure 7.**

7. The same bottle was then maintained at the immediate paneling vacuum level. The stopwatch was started. The depth of paneling was measured with a ruler by aligning the ruler against the edge of the vertical stand. As the depth of paneling increased, the measuring ruler was moved against the body of the bottle, accordingly. When the measuring ruler read 1/8 inch and 1/4 inch, their supplement bottle, and subjecting it to vacuum. The respective approximate timings were recorded. The extent of deformation of each of the three bottles at a depth of paneling of 1/8 inch and 1/4 inch are shown in **Figures 8** to **13.** When the bottle started to panel to a

depth of 1/4 inch, the approximate center of paneling was marked, using a permanent marker pen. The thickness of the center of paneling was measured later.

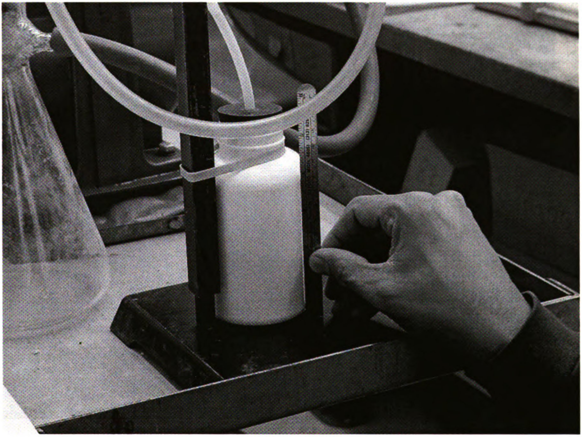

Figure 7. Deformation by 1/32 of an inch

Figure 8. Dietary supplements - depth of paneling of 1/8 inch

Figure 9. Dietary supplement bottle - depth of paneling of 1/4 inch

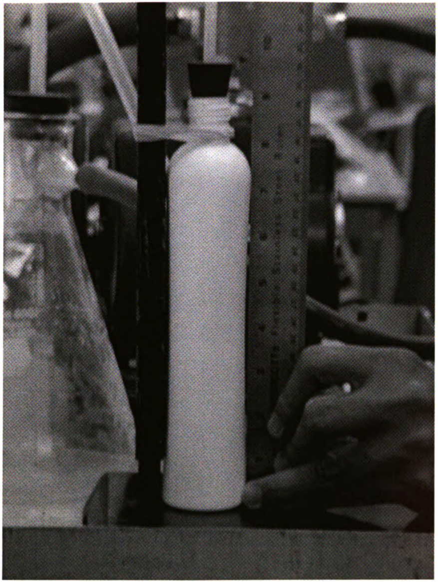

Figure 10. Shampoo - Depth of paneling of 1/8 inch

Figure 11. Shampoo - Depth of paneling of 1/4 inch

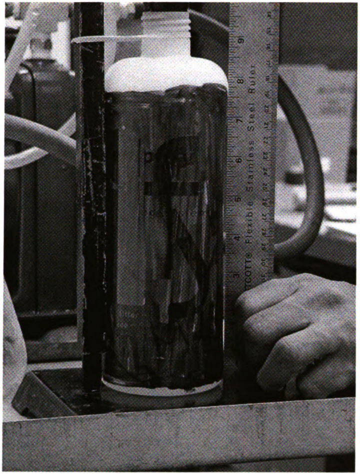

Figure 12. Hair care product bottle - Depth of paneling of 1/8 inch

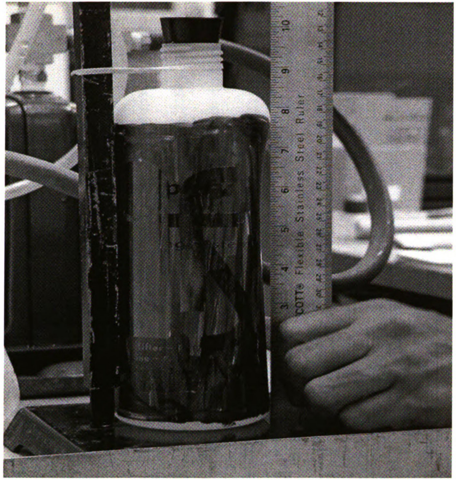

Figure 13. Hair care product bottle - Depth of paneling of 1/4 inch

CHAPTER 4

Data and Results

All three bottles (shampoo, dietary supplements and hair care products) had varying thickness (axially and circumferentially) of the body wall as shown in **Tables 2, 3** and **4**. The thickness of the body wall measured from 0.0305 inch to 0.0528 inch for shampoo bottles, 0.0345 inch to 0.0503 inch for dietary supplement bottles and from 0.0295 inch to 0.0434 inch for the hair care product bottles.

The average wall thicknesses around the circumference for samples of the three bottles are shown in **Tables 5, 6** and **7**. In the case of shampoo bottles, all samples have shown a decrease in thickness from the heel to the shoulder of the bottle. For dietary supplement bottles, 7 of the 10 samples measured initially showed an increase in thickness and then a decrease in thickness from the heel to the shoulder of the bottle. For hair care product bottles, all samples have shown a decrease in thickness from the heel to the shoulder of the bottle.

The vacuum ranges required to panel shampoo bottles, dietary supplement bottles and hair care product bottles were 150-165 mmHg, 220-230 mmHg and 40-55 mmHg respectively as shown in **Tables 8, 9** and **10**. The differences in vacuum levels between these three bottles are substantial. There

Table 2. Shampoo bottles - Body thickness measurements, inches

Samples	Directions	1st point	2nd point	3rd point	4th point
*	**	At 1.5"	At 3"	At 4.5"	At 6"
C1-S1	Upper	0.0445	0.0395	0.0382	0.0343
	Right side	0.0490	0.0528	0.0408	0.0378
	Lower	0.0420	0.0406	0.0379	0.0341
	Left side	0.0422	0.0378	0.0356	0.0330
C1-S2	Upper	0.0447	0.0400	0.0395	0.0354
	Right side	0.0492	0.0493	0.0405	0.0372
	Lower	0.0420	0.0412	0.0375	0.0337
	Left side	0.0429	0.0389	0.0368	0.0336
C2-S1	Upper	0.0420	0.0397	0.0362	0.0324
	Right side	0.0436	0.0495	0.0352	0.0305
	Lower	0.0417	0.0389	0.0360	0.0321
	Left side	0.0451	0.0413	0.0385	0.0355
C2-S2	Upper	0.0468	0.0440	0.0407	0.0350
	Right side	0.0467	0.0522	0.0371	0.0330
	Lower	0.0427	0.0407	0.0396	0.0344
	Left side	0.0482	0.0454	0.0425	0.0377

* A sample is identified by cavity number and sample number. Example, C1-S1 refers to sample number 1 of cavity number 1.

** The direction is made in reference to Figure 4, Chapter 3.

Table 3. Dietary suplement bottles - Body thickness measurements, inches

Samples	Directions	1st point	2nd point	3rd point	4th point
*	**	At 0.75"	At 1.5"	At 2.25"	At 3"
C1-S1	Upper	0.0422	0.0445	0.0412	0.0381
	Right side	0.0422	0.0416	0.0482	0.0373
	Lower	0.0434	0.0445	0.0425	0.0385
	Left side	0.0462	0.0503	0.0472	0.0395
C1-S2	Upper	0.0435	0.0460	0.0455	0.0393
	Right side	0.0343	0.0436	0.0434	0.0376
	Lower	0.0434	0.0473	0.0461	0.0375
	Left side	0.0492	0.0496	0.0464	0.0393
C2-S1	Upper	0.0345	0.0437	0.0430	0.0377
	Right side	0.0461	0.0466	0.0458	0.0397
	Lower	0.0409	0.0418	0.0430	0.0388
	Left side	0.0458	0.0493	0.0472	0.0393
C2-S2	Upper	0.0437	0.0433	0.0430	0.0372
	Right side	0.0471	0.0468	0.0462	0.0406
	Lower	0.0418	0.0423	0.0430	0.0385
	Left side	0.0463	0.0481	0.0472	0.0392
C3-S1	Upper	0.0370	0.0392	0.0404	0.0358
	Right side	0.0478	0.0492	0.0491	0.0416
	Lower	0.0480	0.0493	0.0492	0.0431
	Left side	0.0423	0.0444	0.0456	0.0413
C3-S2	Upper	0.0389	0.0397	0.0396	0.0352
	Right side	0.0465	0.0476	0.0478	0.0416
	Lower	0.0433	0.0456	0.0471	0.0381
	Left side	0.0450	0.0469	0.0475	0.0410
C4-S1	Upper	0.0423	0.0441	0.0451	0.0389
	Right side	0.0492	0.0481	0.0461	0.0402
	Lower	0.0437	0.0441	0.0432	0.0395
	Left side	0.0430	0.0441	0.0436	0.0381
C4-S2	Upper	0.0406	0.0435	0.0449	0.0365
	Right side	0.0477	0.0475	0.0466	0.0388
	Lower	0.0437	0.0434	0.0434	0.0370
	Left side	0.0442	0.0432	0.0434	0.0375
C5-S1	Upper	0.0440	0.0468	0.0466	0.0387
	Right side	0.0481	0.0491	0.0453	0.0385
	Lower	0.0442	0.0462	0.0456	0.0387
	Left side	0.0405	0.0438	0.0441	0.0377
C5-S2	Upper	0.0430	0.0464	0.0461	0.0402
	Right side	0.0500	0.0498	0.0460	0.0384
	Lower	0.0442	0.0466	0.0468	0.0393
	Left side	0.0402	0.0434	0.0437	0.0376

* A sample is identified by cavity number and sample number.
Example, C1-S1 refers to sample number 1 of cavity number 1.

** The direction is made in reference to Figure 4, Chapter 3.

Table 4. Hair Care Product bottles - Body thickness measurements, inches

Samples	Directions	1st point	2nd point	3rd point	4th point
*	**	At 2"	At 3.5"	At 5"	At 6.5"
C1-S1	Upper	0.0400	0.0380	0.0409	0.0384
	Right side	0.0418	0.0379	0.0359	0.0363
	Lower	0.0433	0.0366	0.0368	0.0332
	Left side	0.0375	0.0329	0.0324	0.0309
C1-S2	Upper	0.0399	0.0382	0.0398	0.0353
	Right side	0.0434	0.0402	0.0380	0.0357
	Lower	0.0416	0.0370	0.0346	0.0332
	Left side	0.0384	0.0338	0.0349	0.0332
C2-S1	Upper	0.0380	0.0390	0.0344	0.0352
	Right side	0.0450	0.0403	0.0386	0.0369
	Lower	0.0440	0.0376	0.0360	0.0332
	Left side	0.0396	0.0344	0.0332	0.0319
C2-S2	Upper	0.0389	0.0386	0.0396	0.0353
	Right side	0.0418	0.0404	0.0401	0.0364
	Lower	0.0422	0.0370	0.0355	0.0323
	Left side	0.0382	0.0332	0.0318	0.0311
C3-S1	Upper	0.0430	0.0402	0.0402	0.0390
	Right side	0.0442	0.0368	0.0370	0.0354
	Lower	0.0418	0.0358	0.0350	0.0320
	Left side	0.0400	0.0344	0.0336	0.0328
C3-S2	Upper	0.0398	0.0387	0.0377	0.0355
	Right side	0.0416	0.0381	0.0372	0.0353
	Lower	0.0415	0.0371	0.0355	0.0324
	Left side	0.0378	0.0338	0.0326	0.0309
C4-S1	Upper	0.0430	0.0375	0.0375	0.0384
	Right side	0.0441	0.0400	0.0386	0.0362
	Lower	0.0439	0.0365	0.0364	0.0323
	Left side	0.0397	0.0334	0.0321	0.0308
C4-S2	Upper	0.0410	0.0382	0.0376	0.0350
	Right side	0.0440	0.0392	0.0382	0.0354
	Lower	0.0402	0.0352	0.0352	0.0311
	Left side	0.0380	0.0330	0.0326	0.0301
C5-S1	Upper	0.0411	0.0386	0.0376	0.0360
	Right side	0.0423	0.0397	0.0375	0.0360
	Lower	0.0428	0.0376	0.0345	0.0323
	Left side	0.0397	0.0358	0.0344	0.0332

Table 4. (Continued)

Samples *	Directions **	1st point At 2"	2nd point At 3.5"	3rd point At 5"	4th point At 6.5"
C5-S2	Upper	0.0395	0.0369	0.0356	0.0340
	Right side	0.0415	0.0396	0.0385	0.0371
	Lower	0.0392	0.0357	0.0338	0.0319
	Left side	0.0352	0.0329	0.0318	0.0295
C6-S1	Upper	0.0433	0.0412	0.0395	0.0391
	Right side	0.0421	0.0422	0.0375	0.0358
	Lower	0.0426	0.0373	0.0345	0.0331
	Left side	0.0387	0.0349	0.0320	0.0309
C6-S2	Upper	0.0392	0.0373	0.0345	0.0344
	Right side	0.0415	0.0397	0.0382	0.0384
	Lower	0.0405	0.0359	0.0333	0.0331
	Left side	0.0361	0.0338	0.0303	0.0331
C7-S1	Upper	0.0440	0.0392	0.0368	0.0351
	Right side	0.0428	0.0385	0.0364	0.0361
	Lower	0.0421	0.0362	0.0338	0.0323
	Left side	0.0382	0.0336	0.0324	0.0311
C7-S2	Upper	0.0391	0.0375	0.0361	0.0353
	Right side	0.0426	0.0396	0.0393	0.0356
	Lower	0.0422	0.0366	0.0344	0.0326
	Left side	0.0377	0.0335	0.0325	0.0315
C8-S1	Upper	0.0382	0.0373	0.0361	0.0461
	Right side	0.0332	0.0361	0.0293	0.0331
	Lower	0.0366	0.0370	0.0330	0.0402
	Left side	0.0376	0.0380	0.0360	0.0420
C8-S2	Upper	0.0430	0.0390	0.0365	0.0431
	Right side	0.0341	0.0367	0.0306	0.0348
	Lower	0.0380	0.0378	0.0348	0.0421
	Left side	0.0382	0.0367	0.0352	0.0420
C9-S1	Upper	0.0404	0.0405	0.0371	0.0397
	Right side	0.0415	0.0397	0.0396	0.0362
	Lower	0.0424	0.0380	0.0350	0.0340
	Left side	0.0370	0.0352	0.0335	0.0332
C9-S2	Upper	0.0409	0.0414	0.0411	0.0392
	Right side	0.0432	0.0403	0.0402	0.0390
	Lower	0.0432	0.0357	0.0347	0.0322
	Left side	0.0380	0.0342	0.0333	0.0320

* A sample is identified by cavity number and sample number. Example, C1-S1 refers to sample number 1 of cavity number 1.

** The direction is made in reference to Figure 4, Chapter 3.

Table 5. **Shampoo bottles-Average body thickness measured circumferentially from heel to shoulder, inches**

Samples	1st point	2nd point	3rd point	4th point
	At 1.5"	At 3"	At 4.5"	At 6"
C1-S1	0.0444	0.0427	0.0381	0.0348
C1-S2	0.0447	0.0424	0.0386	0.0350
C2-S1	0.0431	0.0424	0.0365	0.0326
C2-S2	0.0461	0.0456	0.0400	0.0350

Table 6. **Dietary supplement bottles-Average body thickness measured circumferentially from heel to shoulder, inches**

Samples	1st point	2nd point	3rd point	4th point
	At 0.75"	At 1.5"	At 2.25"	At 3"
C1-S1	0.0435	0.0452	0.0448	0.0384
C1-S2	0.0426	0.0466	0.0454	0.0384
C2-S1	0.0418	0.0454	0.0448	0.0389
C2-S2	0.0447	0.0451	0.0449	0.0389
C3-S1	0.0438	0.0455	0.0461	0.0405
C3-S2	0.0434	0.0450	0.0455	0.0390
C4-S1	0.0446	0.0451	0.0445	0.0392
C4-S2	0.0441	0.0444	0.0446	0.0375
C5-S1	0.0442	0.0465	0.0454	0.0384
C5-S2	0.0344	0.0466	0.0457	0.0389

Table 7. **Hair care product bottles-Average body thickness measured circumferentially from heel to shoulder, inches**

Samples	1st point	2nd point	3rd point	4th point
	At 2"	At 3.5"	At 5"	At 6.5"
C1-S1	0.0407	0.0364	0.0365	0.0347
C1-S2	0.0408	0.0373	0.0368	0.0344
C2-S1	0.0417	0.0378	0.0356	0.0343
C2-S2	0.0403	0.0373	0.0368	0.0338
C3-S1	0.0423	0.0373	0.0365	0.0348
C3-S2	0.0402	0.0369	0.0358	0.0335
C4-S1	0.0427	0.0369	0.0362	0.0344
C4-S2	0.0408	0.0364	0.0359	0.0329
C5-S1	0.0415	0.0379	0.0360	0.0344
C5-S2	0.0389	0.0363	0.0349	0.0331
C6-S1	0.0417	0.0389	0.0359	0.0347
C6-S2	0.0393	0.0367	0.0341	0.0348
C7-S1	0.0418	0.0369	0.0349	0.0337
C7-S2	0.0404	0.0368	0.0356	0.0338
C8-S1	0.0364	0.0371	0.0336	0.0404
C8-S2	0.0377	0.0376	0.0343	0.0405
C9-S1	0.0403	0.0384	0.0363	0.0358
C9-S2	0.0413	0.0379	0.0373	0.0356

was paneling in two places on the shampoo bottle, three places on the dietary supplement bottle and in a single place on the hair care product bottles.

The time required to panel the bottle to depths of 1/8 inch and 1/4 inch are also shown in **Tables 8, 9** and **10.** The vacuum and time ranges required to panel the shampoo bottles, dietary supplement bottles and hair care product bottles to a depth of 1/8 inch and 1/4inch are shown in **Table 11**.

For all three bottles, the time required to deform to 1/4 inch from 1/8 inch was very short compared to the time required to deform from 1/32 inch to 1/8 inch.

Figures 14, 15 and 16 show the location of paneling at maximum depth on the body wall for shampoo bottle, dietary supplement bottle and hair care product bottle respectively. These figures also show thickness of the body of the bottle where the maximum depth of paneling had taken place.

For shampoo bottles, the location of paneling is above the mid-point of the body height of 7 inches. The location of paneling was between 3.75 inches and 4.75 inches. The location of paneling for cavity one is higher than cavity two. These locations are in the region of the thinner section of the body wall.

Table 8. Shampoo bottles - Vacuum testing values and time taken to panel

Samples	Vacuum to cause immediate paneling (mmHg)	Time taken to panel depth 1/8" at same vacuum (min)	Time taken to panel depth 1/4" at same vacuum (min)
C1-S1	160	30.1	30.2
C1-S2	155	12.4	12.5
C2-S1	150	61.7	61.8
C2-S2	165	81.5	87.4

Table 9. Dietary Supplement bottles - Vacuum testing values and time taken to panel

Samples	Vacuum to cause immediate paneling (mmHg)	Time taken to panel depth 1/8" at same vacuum (min)	Time taken to panel depth 1/4" at same vacuum (min)
C1- S1	230	45.1	45.3
C1- S2	220	62.7	63.3
C2-S1	230	51.2	51.7
C2-S2	230	63.7	63.9
C3-S1	230	51.5	51.7
C3-S2	230	25.0	25.2
C4-S1	220	37.3	37.5
C4-S2	220	32.4	32.8
C5-S1	230	73.4	73.6
C5-S2	230	33.5	33.7

Table 10. Hair Care Product bottles - Vacuum testing values and time taken to panel

Samples	Vacuum to cause immediate paneling (mmHg)	Time taken to panel depth 1/8" at same vacuum (min)	Time taken to panel depth 1/4" at same vacuum (min)
C1- S1	40	12.8	13.2
C1- S2	45	20.7	21.6
C2-S1	45	23.0	23.9
C2-S2	55	9.7	10.0
C3-S1	55	6.5	6.7
C3-S2	50	5.7	5.9
C4-S1	45	13.5	13.9
C4-S2	50	3.7	3.9
C5-S1	45	16.8	17.3
C5-S2	45	4.4	4.6
C6-S1	40	22.3	22.6
C6-S2	40	17.7	18.2
C7-S1	45	15.8	16.1
C7-S2	45	5.6	6.0
C8-S1	40	19.6	20.0
C8-S2	45	17.4	17.6
C9-S1	45	14.5	14.9
C9-S2	45	12.5	12.9

Table 11. Vacuum and time ranges required to panel

Bottles	Vacuum to cause immediate paneling (mmHg)	Time range to panel depth 1/8" (min)	Time range to panel depth 1/8" (min)
Shampoo	150-165	12.4-81.5	0.1 *
Dietary supplement	220-230	25-73.4	0.2-0.6
Hair care product	40-55	3.7-22.3	0.2-0.9

* Except for sample C2-S2 which took 5.9 minutes

Samples	1st point At 1.5"	2nd point At 3"		3rd point At 4.5"		4th point At 6"
C1-S1	0.0444	0.0427		0.0381	At 4.625 0.0353	0.0348
C1-S2	0.0447	0.0424		0.0386	At 4.75 0.036	0.0350
C2-S1	0.0431	0.0424	At 3.75 0.0393	0.0365		0.0326
C2-S2	0.0461	0.0456	At 4.25 0.0385	0.0400		0.0350

Note : 1 Flat body height of the bottle = 7"
2 Location of paneling and thickness of the body where maximum depth of paneling had taken place

Figure 14. Mapping of paneling : Shampoo bottles
Location of paneling and wall thicknesses are shown inside the heavy lines. Four points (1.5 ", 3", 4.5" and 6") are the distances above the heel (see Figure 4). The other values are the average wall thicknesses at that height above the heel.

Samples	1st point At 0.75	2nd point At 1.5"		3rdpoint At 2.25"	4th point At 3"
C1-S1	0.0435	0.0452	At 2" 0.0409	0.0448	0.0384
C1-S2	0.0426	0.0466	At 2" 0.0425	0.0454	0.0384
C2-S1	0.0418	0.0454	At 2" 0.0417	0.0448	0.0389
C2-S2	0.0447	0.0451	At 2" 0.0383	0.0449	0.0389
C3-S1	0.0438	0.0455	At 2" 0.0399	0.0461	0.0405
C3-S2	0.0434	0.0450	At 2" 0.0405	0.0455	0.0390
C4-S1	0.0446	0.0451	At 2" 0.0446	0.0455	0.0392
C4-S2	0.0441	0.0444	At 2" 0.0436	0.0446	0.0375
C5-S1	0.0442	0.0465	At 2.125" 0.0422	0.0454	0.0384
C5-S2	0.0344	0.0466	At 2.125" 0.0421	0.0457	0.0389

Note: 1 Flat body height of the bottle = 3.5"

2 $\boxed{\quad\quad}$ Location of paneling and thickness of the body where maximum depth of paneling had taken place

Figure 15: Mapping of paneling : Dietary supplement bottles
Location of paneling and wall thicknesses are shown inside the heavy lines. Four points (1.5", 3", 4.5" and 6") are the distances above the heel (see Figure 4). The other values are the average wall thicknesses at that height above the heel.

Samples	1st point At 2"	2nd point At 3.5"		3rd point At 5"		4th point At 6.5"
C1-S1	0.0407	0.0364		0.0365	At 5.25" 0.031	0.0347
C1-S2	0.0408	0.0373		0.0360	At 5" 0.0325	0.0344
C2-S1	0.0417	0.0378		0.0356	At 5" 0.0356	0.0343
C2-S2	0.0403	0.0373		0.0368	At 5" 0.0316	0.0338
C3-S1	0.0423	0.0373		0.0365	At 5" 0.0311	0.0348
C3-S2	0.0402	0.0369		0.0358	At 5" 0.0334	0.0325
C4-S1	0.0427	0.0369		0.0362	At 5" 0.0324	0.0344
C4-S2	0.0408	0.0364		0.0359	At 5" 0.0333	0.0329
C5-S1	0.0415	0.0379		0.0360	At 5.25" 0.0324	0.0344
C5-S2	0.0389	0.0363		0.0349	At 5" 0.0332	0.0331
C6-S1	0.0417	0.0389		0.0359	At 5.25" 0.0310	0.0347
C6-S2	0.0393	0.0367		0.0341	At 5.25" 0.0300	0.0348
C7-S1	0.0418	0.0369		0.0349	At 5.25" 0.0346	0.0337
C7-S2	0.0404	0.0368		0.0356	At 5.25" 0.0318	0.0338
C8-S1	0.0364	0.0371	At 4.75" 0.0294	0.0336		0.0404
C8-S2	0.0377	0.0376	At 4.75" 0.0289	0.0343		0.0405
C9-S1	0.0403	0.0384		0.0363	At 5" 0.0331	0.0358
C9-S2	0.0413	0.0379		0.0373	At 5.25" 0.0334	0.0356

Note: 1 Flat body height of the bottle = 7.5"

2 Location of paneling and thicknessof the body where maximum depth of paneling had taken place

Figure 16. Mapping of paneling : Hair care product bottles
Location of paneling and wall thicknesses are shown inside the heavy lines. Four points (1.5", 3", 4.5" and 6") are the distances above the heel (see Figure 4). The other values are the average wall thicknesses at that height above the heel.

For dietary supplement bottles, the location of paneling is 0.25 inch above the mid-point of the body height of 3.5 inches.

For hair care product bottles, the location of paneling is above the mid-point of the body height of 7.5 inches. The location of paneling was between 4.75 inches and 5.25 inches. The location of paneling of cavity eight is lower than the other cavities. These locations are in the region of the thinner section of the body.

The vacuum level of 40-55 mmHg to cause paneling of hair care product bottles was much lower than the partial pressure of atmospheric oxygen (159.5 mmHg). The vacuum level of 150-165 mmHg to cause the paneling of shampoo bottles was almost the same as the partial pressure of atmospheric oxygen. The vacuum level of 220-230 mmHg to cause the paneling of dietary supplement bottles was higher than the partial pressure of atmospheric oxygen.

A dietary supplement bottle that had paneled with product in it was evaluated to determine whether pressure differential due to the removal of oxygen from the headspace could be the cause of paneling. Removal of oxygen by the product had been suggested as a cause of paneling. The calculations are as follows:

Overflow volume of the deformed bottle was 413 ml.

Total volume of the product was 314 ml.

Therefore, the headspace volume of the deformed bottle was 99ml (413-314).

Overflow volume of an undeformed bottle was 430 ml.

Therefore, the headspace volume of the undeformed bottle was 116 ml (430-314).

So the reduction in the headspace volume as a result of deformation was 17 ml (116-99).

If all the oxygen from the original headspace was removed without changing the headspace volume, then the pressure would drop to 600 mmHg (79% of 760 mmHg), thus allowing the headspace volume to shrink until the pressure goes back to 760 mmHg. Oxygen occupied 21% of 116 ml, which is equal to 24 ml. So, if there is a complete removal of oxygen, the headspace volume would drop by 24 ml.

Sorption of 71% (17/24 X 100%) of oxygen in the headspace could account for the volume change. Therefore, the pressure of oxygen in the container would have been 113.32 mmHg (760 mmHg X 0.21 X 0.71). The headspace in the container would have nitrogen at 600 mmHg (0.78 x 760 mmHg) and oxygen at 113 mmHg for a total of 713 mmHg internal pressure. This would have caused a pressure differential of 47 mmHg between inside and outside of the container, thus causing the container to panel.

CHAPTER 5

Conclusion and Future Work

The experiments on vacuum evacuation of shampoo, dietary supplements and hair care product bottles showed that a pressure differential is one of the possible causes of paneling of the bottle. The creep (the time dependent increase in strain under sustained stress) can influence the paneling significantly. The location of paneling where the paneling has reached a maximum depth showed that its location is above the mid-point of the flat body height for shampoo bottles and hair care product bottles. However, there was no indication of the influence of thickness variation on paneling.

A possible cause of underpressure in the headspace for all three bottles (shampoo, dietary supplement and hair care product) was removal of oxygen. The maximum pressure differential would be about 160 mmHg, if all the oxygen were removed from the headspace. This could have been the case for the hair care product and the shampoo product. However, in the case of dietary supplement, the vacuum level of 220-230 mmHg required to panel the bottle is greater than the pressure differential resulting from removal (sorption) of oxygen.

All three products showed that the creep had significantly influenced paneling. As mentioned in **Chapter 4,** all three bottles took a long time to panel from a depth of 1/32 inch to a depth of 1/8 inch and a very short time to panel from 1/8 inch to a depth of 1/4 inch.

It can be said that the two factors, i.e. pressure differential and creep, played a combined role rather than an individual role in causing the paneling of plastic bottles.

The manufacturer's request for a solution to the paneling problem can be approached by using the questions guide mentioned in **Appendix A.** With this **guide** we will be able to analyze the causes of paneling and develop an appropriate solution to solve the paneling problem.

The design of the bottle is also important to minimize or avoid paneling. The design includes the size, shape and thickness distribution. The bottle may be made more resistant to deformation by incorporating stress absorbing strips as described in **Chapter 1** (literature review) .

The vacuum test can be used to evaluate the resistance of bottles to paneling, during the development of new packages. It also can be used to check incoming quality control based on sampling, to ensure that the bottles will not panel after filling, until sold.

A study is needed to evaluate the influence of thickness variation on paneling. Therefore, future study on paneling of plastic bottles may include the following areas:

The influence of thickness variation on paneling.

(1) The influence of temperature on paneling.

(2) The determination of the percentage of oxygen in the headspace of the paneled bottles.

(3) The determination of the increase in volume in the headspace, due to reduction in the volume of the product. (This may be caused by product loss through permeation or by product shrinkage, which may have occurred when the product was filled at high temperature, followed by cooling to room temperature).

APPENDIX A

Question Guide for Analyzing the Causes of Paneling in the field

Product:-

1) Type of product

2) Volume of shrinkage upon contraction

3) Reaction with oxygen in the headspace

4) Permeation of product/components through the bottle wall

Bottle:-

1) Material

2) Dimensions and shape

3) Thickness of the body wall

4) Type of closure

5) Type of sealing at the finish

6) Overflow volume

Filling:-

1) Type of filling

2) Temperature during filling

3) Foaming of product during filling

4) Headspace volume

5) Method of capping

6) Time lapse for packing the finished bottles into the shipper

Storage and Distribution:-

1) Type of secondary packaging
2) Type of pallet stacking pattern
3) Storage time of the finished products at the warehouses (factory, distribution and customer)
4) Temperature at the warehouses (factory, distribution and customer)

Paneling:-

1) Location
2) Shape and the magnitude
3) Percentage of paneling in a lot
4) Progressive or sudden collapse
5) Thickness of the section
6) Design of the section
7) Permanency of the distortion
8) Time elapsed after filling
9) Fixed or increased with time
10) Place first observed

APPENDIX B

4 Liter hot filled Ketchup HDPE bottle

Product:-

1) Type of product: **Ketchup**

2) Volume of shrinkage upon contraction: **Not known**

3) Reaction with oxygen in the headspace: **None**

4) Permeation of product/components through the bottle wall: **Water**

Bottle:-

1) Material: **High density polyethylene**

2) Dimensions: **diameter -about 5.90 inches**
   body height-about 5.90 inches
   conical shoulder with hollow handle about 3.14 inches

3) Thickness of the body wall: **0.039-0.043 inch**

4) Type of closure: **screw on polypropylene cap with low density polyethylene inner plug**

5) Type of sealing at the finish: **None**

6) Overflow volume: **about 4320 milliliters**

Filling:-

1) Type of filling: **Volumetric**

2) Temperature during filling: **140°F**

3) Foaming of product during filling: **None**

4) Headspace volume: **about 320 milliliters**

5) Method of capping: **Manual inner plug insertion followed by semi-automatic punching; manual capping**

6) Time lapse for packing the finished bottles into the shipper: **Packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Block pattern with no space in between**

3) Storage time of the finished products at the warehouses: **Factory : 3 days**
Distribution: 15-30 days
Customer : 15-30 days

4) Temperature at the warehouses: **Factory : 80-100°F**
Distribution: 80-115°F
Customer : 80-100°F

Paneling:-

1) Location: **Mid section of the body wall**

2) Shape and the magnitude: **Indented**
Length: 1.18 inches
Width : 1.81 inches
Depth : 0.39 inch

3) Percentage of paneling in a lot: **100%**

4) Progressive or sudden collapse: **Progressive**

5) Thickness of the section: **0.039 inch**

6) Design of the section: **Segment of a circle**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **about a week**

9) Fixed or increased with time: **Increased**

10) Place first observed: **Food service outlets**

APPENDIX C

1 Liter and 2 Liter floor cleaner HDPE bottle

Product:-

1) Type of product: **Floor cleaner**

2) Volume of shrinkage upon contraction: **None**

3) Reaction with oxygen in the headspace: **None**

4) Permeation of product/components through the bottle wall: **Solvent and Fragrance**

Bottle:-

1) Material: **High density polyethylene**

2) Dimensions: **1 Liter : Length -about 5.90 inches**
   Width -about 5.90 inches
   Height -about 8.66 inches
   2 Liter : Length -about 3.93 inches
   Width -about 3.14 inches
   Height -about 10.23 inches

3) Thickness of the body wall: **1 Liter : 0.027 inch**
   2 liter : 0.031 inch

4) Type of closure: **screw on polypropylene cap with inner sealing ring**

5) Type of sealing at the finish: **None**

6) Overflow volume: **1 Liter : about 1080 milliliters**
   2 Liter : about 2160 milliliters

Filling:-

1) Type of filling: **Pressure**

2) Temperature during filling: **70°F**

3) Foaming of product during filling: **Foam filled the headspace**

4) Headspace volume: **1 Liter : about 80 milliliters**
2 Liter : about 160 milliliters

5) Method of capping: **Manual cap loading followed by automatic in-line belt wheel**

6) Time lapse for packing the finished bottles into the shipper: **Packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Interlock pattern with no space in between**

3) Storage time of the finished products at the warehouses: **Factory : 3 days**
Distribution: 30 days
Customer : 30 days

4) Temperature at the warehouses: **Factory : 80-100°F**
Distribution: 80-115°F
Customer : 80-100°F

Paneling:-

1) Location: **Front and back label panels**

2) Shape and the magnitude: **Indented**

Length: 1.18 inches

Width : 0.78 inches

Depth : 0.19 inch

3) Percentage of paneling in a lot: **100%**

4) Progressive or sudden collapse: **Progressive**

5) Thickness of the section: **1 Liter : 0.021 inch**

2 liter : 0.031 inch

6) Design of the section: **Flat panel**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **About 3 hours**

9) Fixed or increased with time: **Increased**

10) Place first observed: **Factory warehouse**

APPENDIX D

32 Ounce cleaning product HDPE bottle

Product:-

1) Type of product: **Cleaner product**

2) Volume of shrinkage upon contraction: **None**

3) Reaction with oxygen in the headspace: **None**

4) Permeation of product/components through the bottle wall: **Solvent and Fragrance**

Bottle:-

1) Material: **High density polyethylene**

2) Dimensions: **diameter - 3.62 inches**

   height - 8.93 inches

3) Thickness of the body wall: **0.03 inch**

4) Type of closure: **screw on polypropylene cap with 0.04 inch F-127 PE foam liner**

5) Type of sealing at the finish: **None**

6) Overflow volume: **about 35 ounces**

Filling:-

1) Type of filling: **Piston volumetric**

2) Temperature during filling: **80°F**

3) Foaming of product during filling: **Some products foamed**

4) Headspace volume: **8.5%**

5) Method of capping: **In-line spindle/wheel**

6) Time lapse for packing the finished bottles into the shipper: **Packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Column stacking pattern**

3) Storage time of the finished products at the warehouses:

Factory	**:**	**15-30 days**
Distribution	**:**	**30-60 days**
Customer	**:**	**5-10 days**

4) Temperature at the warehouses:

Factory	**:**	**72°F**
Distribution	**:**	**72-110°F**
Customer	**:**	**72°F**

Paneling:-

1) Location: **Mid section of the bottle**

2) Shape and the magnitude: **Indented**

Length: 3 inches

Width : 2 inches

3) Percentage of paneling in a lot: **100%**

4) Progressive or sudden collapse: **Progressive**

5) Thickness of the section: **0.030 inch**

6) Design of the section: **Segment of circle**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **1-2 weeks**

9) Fixed or increased with time: **Increased**

10) Place first observed: **Factory warehouse**

APPENDIX E

24 Ounce hot filled chocolate syrup HDPE bottle

Product:-

1) Type of product: **Hot filled chocolate syrup**

2) Volume of shrinkage upon contraction: **3%**

3) Reaction with oxygen in the headspace: **None**

4) Permeation of product/components through the bottle wall: **Water**

Bottle:-

1) Material: **High density polyethylene**

2) Dimensions: **Length - 4.5 inches**

   Width - 5.98 inches

   Height - 7.75 inches

3) Thickness of the body wall: **0.020 - 0.060 inch**

4) Type of closure: **Push-pull cap**

5) Type of sealing at the finish: **None**

6) Overflow volume: **about 20 ounces**

Filling:-

1) Type of filling: **Volumetric**

2) Temperature during filling: **185°F**

3) Foaming of product during filling: **None**

4) Headspace volume: **8%**

5) Method of capping: **Rotating mechanical 3 finger capper with three heads**

6) Time lapse for packing the finished bottles into the shipper: **Not packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Column stacking pattern**

3) Storage time of the finished products at the warehouses: **Factory : 12 weeks**
Distribution: N/A
Customer : N/A

4) Temperature at the warehouses: **Factory : 60°F**
Distribution: N/A
Customer : N/A

Paneling:-

1) Location: **Front and back label panels**

2) Shape and the magnitude: **Indented**
Length: N/A
Width : N/A
Depth : N/A

3) Percentage of paneling in a lot: **80%**

4) Progressive or sudden collapse: **Sudden collapse**

5) Thickness of the section: **0.03 inch**

6) Design of the section: **Oval**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **Immediately**

9) Fixed or increased with time: **Fixed**

10) Place first observed: **Filling line**

APPENDIX F

1 Liter hair root lifter HDPE bottle

Product:-

1) Type of product: **Hair care product**
2) Volume of shrinkage upon contraction: **None**
3) Reaction with oxygen in the headspace: **Possible**
4) Permeation of product/components through the bottle wall: **Water**

Bottle:-

1) Material: **High density polyethylene**
2) Dimensions: **diameter - 3.25 inches**
   height - 9.65 inches
3) Thickness of the body wall: **0.018 inch**
4) Type of closure: **33 millimeters/415 polystyrene polycam dispensing closure**
5) Type of sealing at the finish: **None**
6) Overflow volume: **1088 milliliters**

Filling:-

1) Type of filling: **Piston volumetric**
2) Temperature during filling: **72°F**
3) Foaming of product during filling: **Foamed very little**
4) Headspace volume: **8%**
5) Method of capping: **In-line belt/wheel**
6) Time lapse for packing the finished bottles into the shipper: **Packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Interlock stacking pattern**

3) Storage time of the finished products at the warehouses: **Factory : 2 weeks**

   Distribution: 1-2 years

   Customer : 1 year

4) Temperature at the warehouses: **Factory : 72°F**

   Distribution: 72-110°F

   Customer : 72°F

Paneling:-

1) Location: **Mid section of the bottle**

2) Shape and the magnitude: **Indented**

   Length: N/A
   Width : N/A

3) Percentage of paneling in a lot: **100%**

4) Progressive or sudden collapse: **Progressive**

5) Thickness of the section: **0.018 inch**

6) Design of the section: **Segment of circle**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **Immediately**

9) Fixed or increased with time: **Increased**

10) Place first observed: **Filling line**

APPENDIX G

HDPE bottle containing 240 Dietary supplement tablets

Product:-

1) Type of product: **Dietary supplement**

2) Volume of shrinkage upon contraction: **Not known**

3) Reaction with oxygen in the headspace: **Possible**

4) Permeation of product/components through the bottle wall: **None**

Bottle:-

1) Material: **High density polyethylene**

2) Dimensions: **diameter - 3.75 inches**
   height - 5.37 inches

3) Thickness of the body wall: **0.03 inch**

4) Type of closure: 45 **millimeter continuous thread with 0.0293 inch heat seal liner (paper/ aluminum foil/polyethylene)**

5) Type of sealing at the finish: **Liner sealing**

6) Overflow volume: **About 400 milliliters**

Filling:-

1) Type of filling: **Counting**

2) Temperature during filling: **72°F**

3) Foaming of product during filling: **None**

4) Headspace volume: **N/A**

5) Method of capping: **N/A**

6) Time lapse for packing the finished bottles into the shipper: **Packed immediately**

Storage and Distribution:-

1) Type of secondary packaging: **RSC**

2) Type of pallet stacking pattern: **Alternate stacking pattern**

3) Storage time of the finished products at the warehouses: **Factory : 1 month**

   Distribution: 3 months

   Customer : N/A

4) Temperature at the warehouses: **Factory : 72°F**

   Distribution: 72-110°F

   Customer : 72°F

Paneling:-

1) Location: **Mid section of the bottle**

2) Shape and the magnitude: **Indented**

   Length: 3 inches

   Width : 1.5 inches

3) Percentage of paneling in a lot: **100%**

4) Progressive or sudden collapse: **Progressive**

5) Thickness of the section: **0.029 inch**

6) Design of the section: **Segment of circle**

7) Permanency of the distortion: **Permanent**

8) Time elapsed after filling: **15-20 days**

9) Fixed or increased with time: **Increased**

10) Place first observed: **Factory warehouse**

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