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the testing equipment is correctly calibrated. An instrument that is not telling the truth may cause costly rejections.

CONCLUSIONS

Gas detection control systems are all based on the assumption that gas permeation through the material is negligible. This is not the case with small holes unless there is an aluminium barrier included in the packaging material.

The calculations indicate that only microholes well above 10 μm in diameter can be detected in packagings with PE barriers. For barriers including PVDC (Saran) the control system appears to start working at about 2 μm in diameter and has a chance to become accurate in the range well above 3 μm in diameter, assuming the actual microhole length is less than 100 μm. If the hole length is above 100 μm, the detectable diameter is increased correspondingly. Thus, a hole of 300 μm in length, for example a leakage channel through an improper seal, has to be above 5 μm in diameter to be determined accurately by the gas detection control systems at conditions given in the examples.

It should be noted here that gas permeation flow is less sensitive to a change in pressure in relation to the pinhole flow. Thus, by checking whether the total leakage flow rate is rapidly changed or not it can be judged whether the measured gas leakage originates mainly from gas permeation or mainly from a pinhole. It may be an interesting way to increase the sensitivity of these systems. It has been illustrated here that serious errors from gas permeation can be expected if gas leakage detection is applied on packagings without Al foil barriers.

APPENDIX

Flow rates through pinholes

The laminar flow rate given in Figures 1 and 2 has been calculated by Poiseuille's Law

$$J = (\pi \times d^4 \times (P_2^2 - P_1^2))/256 \times L \times \eta \text{ (m}^3\text{/s)} \quad \text{(A1)}$$

where d = hole diameter (m), L = hole length (m), η = dynamic viscosity (N/m^2) and P = pressure differences (Pa).

It has been assumed that the microhole length is constant (100 μm) and that the differential pressure is 0.1 bar, i.e. a pressure of 0.9 at the outside and 1.0 at the inside of the package. It has also been assumed that 10% of the gas is He or CO_2. For simplicity, the He gas mix has been assumed to have the same viscosity as He and the CO_2 gas mix has been assumed to have the same viscosity as CO_2.

In a literature review by Bojkow[3] a formula for transition flow is given. If the microhole diameter is very much reduced, the Knudsen diffusion (Knudsen flow) phenomenon will control the flow rate. The mass flow rate at such conditions can be expressed as follows

$$J = (D_k \times \Delta P \times V \times \pi \times d^2)/ \times (R \times T \times L \times 4) \text{(m}^3\text{/s)} \quad \text{(A2)}$$

where V = gas volume corresponding to 1 mol of the gas (m^3), P = pressure difference (Pa), R = molar gas constant (J/mole K) and T = temperature (K). The diffusion constant (D_k) *à la* Knudsen is dependent on the actual microhole diameter according to this equation,

$$D_k = (d/3) \times (8 \times R \times T/\pi \times M)^{1/2} \quad \text{(A3)}$$

where M = mass of 1 mol gas (kg/mol).

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PACKAGING TECHNOLOGY AND SCIENCE VOL **4** 21–28 (1991)

Long-life Ambient Food Packaging: a History—from the Tin Can to Plastics and Beyond

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Keywords: Ambient food packaging; metal cans; plastic cans

INTRODUCTION

The preservation of foods by heat dates back to the original Appert paper of 1809; with technical understanding of the preservation process explained by Pasteur in 1860.

Although available, foods processed in this way were only commonly used for military and exploratory expeditions, until the turn of the century and the invention of the *sanitary* can, forerunner of today's *food* can.

Initially, cans were hand made, with the average tinsmith turning out 10 cans a day, the end product requiring a chisel to open it—a far cry from today's convenience food packaging (see Figure 1).

Since the 1930s canned foods have formed part of the staple diet with over 6000 million cans being sold in the UK alone.

FOOD CANS

The basic format of the metal food can has remained unchanged over the last 50 years, however, a number of technical developments in the 1970s and 1980s have significantly changed aspects of this package.

Most three-piece food cans are now welded rather than soldered; lead-free solder was standard for many years.

Some food cans are now two-piece with the body and makers' end in a single piece produced by either DWI (drawn and wall-ironed) or DRD (draw-redraw) techniques. An increasing number of cans, particularly in Europe, have easy-open, ring-pull ends.

In the future we will continue to see innovation in metal can manufacture, with features such as shape, easier opening and polymer laminations being developed for what is clearly an economic, effective and universally accepted packaging system.

GLASS JARS

Glass jars—a corked jar was used in Appert's experiments—are widely used for heat-sterilized products throughout the world, mainly for babyfood, and fruit and vegetable products where appearance is important. The format for jars has changed little over the years, the major development being in shaping, lightweighting and type of closure used: (see Figure 2). In the last 18 months we have seen the introduction of tamper evident features to most glass packages in the UK, such as the combination of a shrink sleeve and a safety button on babyfood packs.

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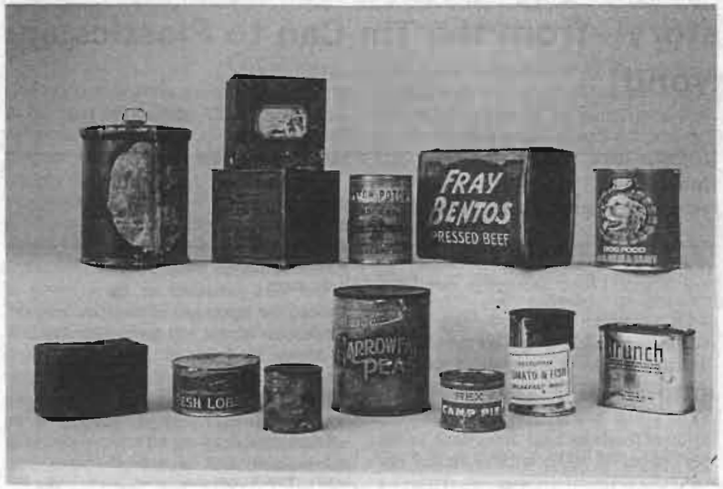

Figure 1. Early cans

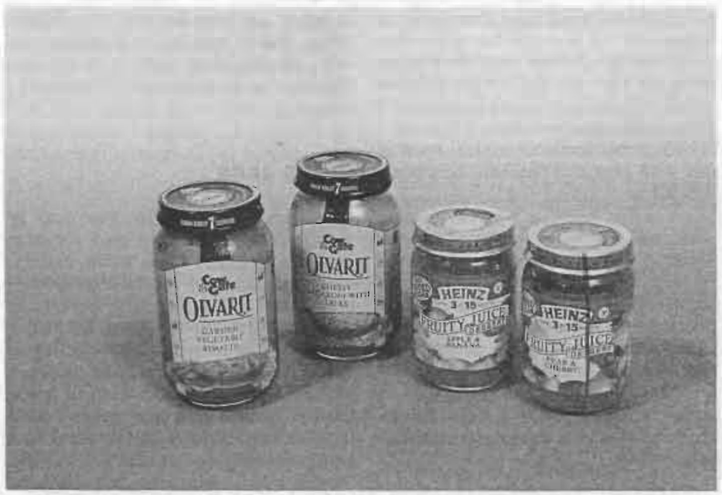

Figure 2. Typical glass jars

REPORT POUCHES

One of the first of a new generation of alternatives to the conventional can to be developed was the retort pouch, a thin, flexible, heat-sealed pouch produced from high-barrier polymer and, generally, aluminium-foil-bearing laminates. The retort pouch is used extensively in Japan for retail packs and in the USA for military feeding, but has failed to establish any significant broad retail success in Europe. The key features of the retort pouch are its lightweight, thin profile for rapid heat processing, and hence good product quality, and its flexibility and durability. The handling of the pouch when hot, its unsuitability for microwave use, the low production speeds and other competitive semi-rigid packages have all limited the pouches' acceptance.

ALUMINIUM FOIL TRAYS

The heat-sealed aluminium foil tray has seen a slow but steady growth of use, mainly in the ready meals and petfood market areas. These containers are established in both retail and military markets, where microwavability, or ease of opening, are not important benefits, but where superior shelf-life over high-barrier plastics can be exploited.

HIGH-BARRIER PLASTICS PACKAGING

The major area of technological innovation, development and investment has been in barrier plastics forming and manufacturing processes.

Initially stimulated by the oil boom of the 1960s and 1970s and the concept of a 'cheap' plastic alternative to the metal can, there has since been the commercialization of a number of attractive alternative packaging formats with an emphasis on functionality and variety, rather than cost.

The production of a marketable pack containing a heat-processed, low acid foodstuff requires a satisfactory combination of a number of key elements.

(i) Fundamental container construction:
  (a) barrier/shelf-life performance;
  (b) extraction/taint and odour.
(ii) Closing method:
  (a) type of closure;
  (b) pack integrity.
(iii) Product/processing regime:
  (a) ingoing product quality;
  (b) process method;
  (c) post-process handling/distribution.

The majority of the new plastic packages used for heat-processed foods are produced from multilayer laminate structures based around polypropylene as the structural polymer.

Although detailed structures may vary in proportions, most contain an oxygen barrier layer of either EVOH (ethylvinylalcohol) or PVdC (polyvinylidene chloride) (Saran® TM*); adhesive layers tying the structure together, and in many cases a reclaim layer produced from excess material generated in the manufacturing process.

In the early 1970s work begun in the area of extruding multilayer laminates to produce sheet from which the initial containers would be formed. The first approach to the market was one of forming plastic can replacements, however, although extensive test packaging, integrity testing and shelf-life evaluation was carried out, there was no real commercial exploitation. A number of factors can be associated with this decision.

(i) The pack was more expensive than a traditional can.
(ii) Product shelf-life was less than a traditional can.
(iii) Packs required overpressure processing with precise control, which was not commonly available at the time; low-cost microprocessors only became available from the mid-1980s.
(iv) Microwave oven penetration was insignificant and therefore this could not be recognized as a benefit.

The development of high-integrity heat sealing and of CMBs 'Tor' closing process opened up the opportunity for commercial testing of products in alternative shapes of 'Lamipac' barrier containers. The 'Tor' closing process is a patented vacuum closing process, which deforms the lidding material after sealing, to produce a virtually hydraulically solid 'stress-free' pack. This process offered the following technical benefits.

(i) Simplified retort process schedules; particularly important prior to the advent of microprocessor retort control systems.

*Saran is a trade mark of the Dow Chemical Co. Ltd.

(ii) Reduced heat process times equals better product quality.
(iii) Increased resistance to abuse and stress on the seal and lidding material; particularly resistance to foil pin-holing created by pressure heating during processing.
(iv) Increased product shelf-life.
(v) Improved pack appearance.

The first commercial products to be test marketed in this new packaging format were Campbell's Chicken in White Sauce in 1983 and Shippam's three chicken meals in 1984.

In 1985 and 1986 we saw market activity in the USA and in Germany with the start of what was to become Europe's largest market for 'ready meals'.

In the USA we saw the first launch of the Omni can, a double-seamed container produced by American National Can. This package is co-injection moulded with an EVOH barrier material and desiccant to counteract the barrier loss of the EVOH as a result of moisture absorption. Omni also features an aneroid base panel, which relieves pressure generated internally during the retort process by flexing outwards to increase internal-volume, and then reverting after the cooling cycle.

Soon after the launch of Omni came the Dial Corporation Lunch Bucket. This container was again a PP/EVOH/PP container with a double-seamed metal end, but focused directly at the microwavable snack market. The initial Lunch Bucket containers were thermoformed by DRG and after processing were shrink labelled with an expanded polystyrene (EPS) label to provide insulation whilst holding the container to eat from it. The total package also features an injection-moulded overcap to act as a microwave splash-guard (see Figure 3).

These two products heralded the start of a high-volume microwavable snack market, which in 1989 in the USA reached 240 million units and in 1990 looks set to rise to around 350 million units. Three major food processors dominate this market, Dial Corporation, American Home Foods and Hormel with new product launches taking place on a regular basis. The attraction of this packaging format to the USA appears to be the high line throughputs achieved, and hence low production costs versus heat-sealed tray alternatives, and the use of can double-seaming technology fitting the natural

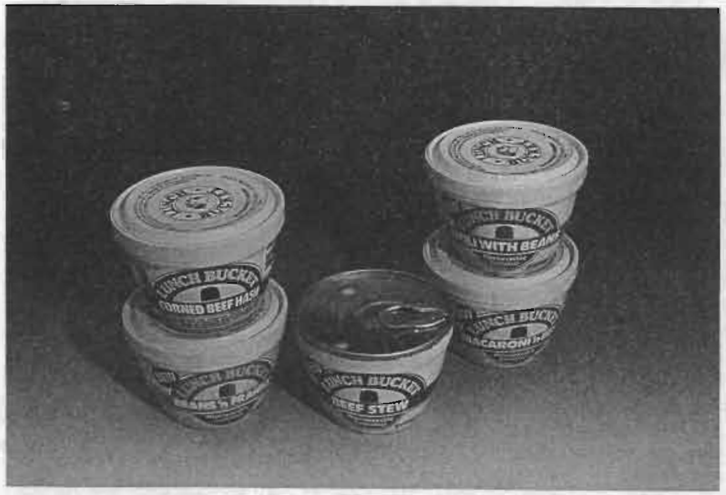

Figure 3. Lunch bucket container

conservatism of the USA canning industry. In addition, the significant microwave oven penetration at the time of launch created greater market opportunities.

The products in Germany were generally full meals in two or three compartment trays, which were atmospherically closed by a foil structure that required cutting with a knife to remove it from the container.

In 1987 we saw a significant number of breakthroughs, with the scaling-up and commerical launch of key products, such as:

(i) 'Sheba' premium catfood. The plastic package was a 125 g Lamipac 'Tor' closed container —unique in that it was a printed container —and although initially launched with a fused sealed lid, in 1988 this became a peelable closure.
(ii) Boots Shapers. The first of the microwavable ready meals to be nationally launched in the UK, directly replacing an aluminium foil tray as packaging format.
(iii) Hormel's Top Shelf. A range of ready meals launched in the USA in a cream pigmented, high-barrier tray, with an induction sealed closure and a unique ring-pull, easy-open feature. This product is now the first ambient ready meal to be available nationally in the USA.
(iv) Impromptu. A range of ready meals launched by Kraft General Foods in a PET tray that does not feature any specific additional barrier. This product was the first dual ovenable package, and although marketed as Perfect Timing in the UK for a short while and ther withdrawn, is now available more widely ir the USA.

In the Autumn of 1988 we saw the launch of the 'Microchef' range of products by Brooke Bond Foods, which has established itself as the leading brand in this market—currently holding around 25% of the total market.

Marks and Spencer became the first retailer to enter this market with a range of meals launched at the end of 1988 in form-fill seal containers sealed with clear barrier lidding material, where product visibility and improved microwave acceptance have to be discounted against reduced shelf-life.

Through 1989 and 1990 in both the UK and the rest of Europe we have seen launches of a whole range of new products in this form of packaging, the market currently segmenting into three key areas.

(i) Premium petfoods. high-barrier packages have now been used for a range of 'Whiskas' premium variety as well as the Sainsbury 'High Society' products (Figure 4).

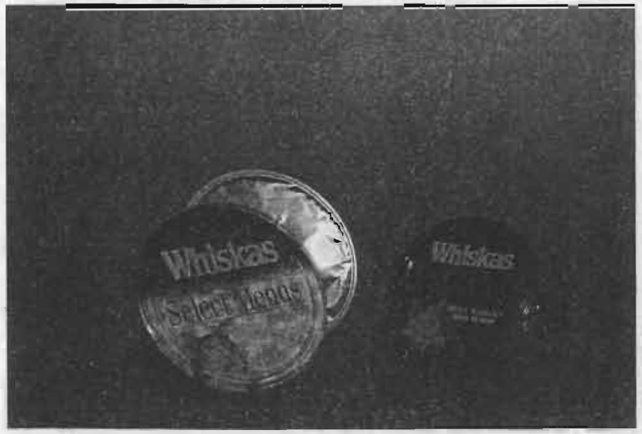

Figure 4. Premium petfood package

(ii) Ready meals. Almost all of the major food retailers now carry a range of 'own label' ready meals in microwavable high-barrier trays, as well as a few specialist branded products such as the John West (fish) (see Figure 5) and Prewetts (vegetarian) meals.

(iii) Snacks. Over the last few months we have seen the launch of a variety of snack products in heat-sealed and double-seamed bowls, generally of lower fill weights than the ready meal products and at a lower price point (Figure 6). Examples of these products are Campbell's take-away and Batchelor's Micro-Chef ranges. The latest launches in double-seamed containers include, Heinz Lunchbowls and Wilson's Micro-Quick, and in New Zealand a range of Hotshot products packed by J. Wattie.

The current market for retortable barrier containers in the UK is around 100 million units per annum, small by comparison to the total market for shelf-stable food products, but growing at a good rate. The UK market currently represents approximately 50% of the total market in Europe.

The number of manufacturers supplying packaging to this market has increased throughout the 1980s. The earliest entrants were CMB through its Lamipac business, followed closely by DRG, American National Can and the Continental Can companies. In France, since the mid-1980s, ONO have dominated high-barrier container and sheet supply, whilst in Germany 4P feature among the leading suppliers.

The UK now has a multitude of potential suppliers, including BXL and Reedpack, exploiting the Australian Hitek thermoforming technology, and more recently Rampart.

A key feature of this type of packaging is the scope for pack differentiation to match a product need or for market identification. Examples of the way this is achieved are:

(i) the range of multicompartmented trays currently produced;
(ii) the general variety of container shapes manufactured.
(iii) alternative closures, foil, clear and opaque films and double-seamed closures;
(iv) contact clarity.

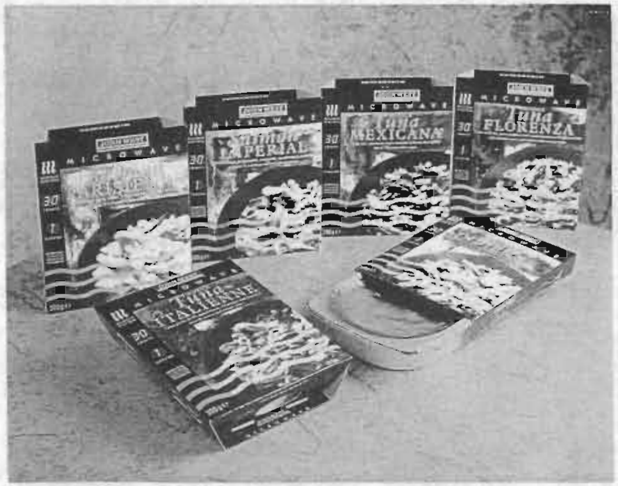

Figure 5. John West fish packs

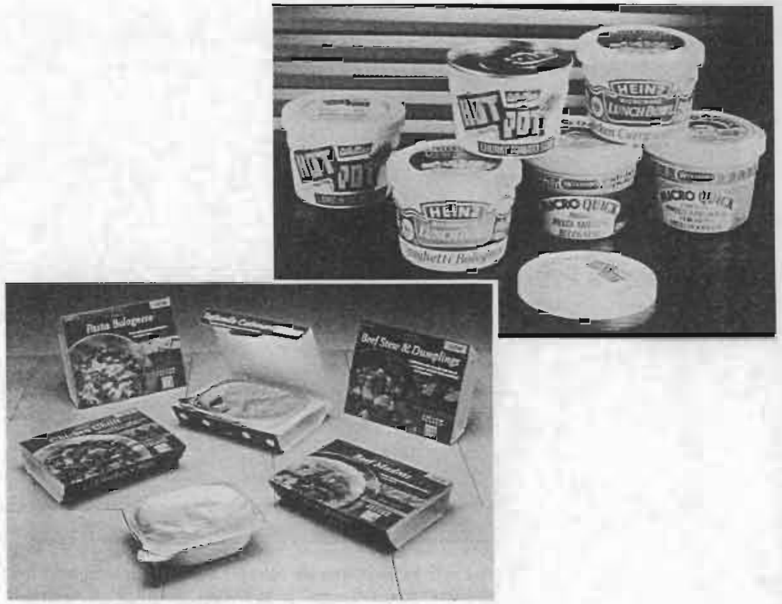

Figure 6. Snack package

A number of other forms of retortable packaging have seen exploitation on a limited scale and represent interesting technical pack concepts, e.g. STEPcan (See Figure 7) and Letpak.

(i) STEPcan. A clear, heat-set PET can, double-seamed with conventional ends, which has been exploited for packing high quality fruit products since 1986. The main product ranges have appeared in Marks & Spencer, where the premium image of the package has been exploited.
(ii) Letpak. A complex composite plastic–foil rectangular can with an easy-open feature made an appearance on the continent during the early 1980s.

ASEPTIC PACKAGING

Aseptic packaging as a process and preservation method has been used for many years, but its scope until recently has been limited by processing and packaging technologies. Developments in the last few years have opened up the range of products that can be processed and filled in this way, and we will inevitably see packaging innovation in the future taking advantage of the opportunities the less demanding aseptic process makes upon the package.

Early aseptic filling was into metal cans and drums, but this was soon followed by the development of the most widely used aseptic package to date—the Tetra brik carton. The composite board carton with its effective use of space, low cost and graphic qualities has proven to be an ideal commodity package for aseptically filled liquids.

Other carton systems include the Combibloc pre-formed carton system and the ODIN carton, which has been specifically developed as an easy-open carton for particulate products.

Plastic pots and trays, both high barrier and monolayer, formfill seal and pre-formed have been used increasingly, particularly for dessert products such as the Ambrosia Creamed Rice pack. It is anticipated that this packaging format will be used

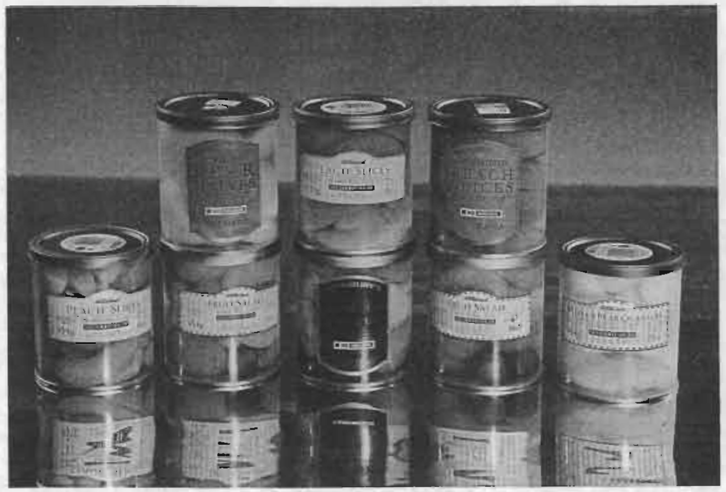

Figure 7. STEPCAN

increasingly as the capabilities to produce particulate aseptic products make this an alternative packaging route to conventional retorting, but with potentially improved product quality.

One unique packaging 'system' for liquid products that is now commercially available is the Freshfill Drinks Can. An injection-moulded polypropylene body seamed with a conventional beverage easy-open end, this container was first tested more than three years ago and is now used for both plain and flavoured milks.

FUTURE DEVELOPMENTS

In the future we anticipate seeing a number of different processing and packaging developments affecting the total shelf-stable foods market.

Aseptic packaging will continue to grow, as will processes such as microwave sterilization—currently in its infancy, with the first commercial products beginning to appear.

The barrier plastics market should continue to see healthy growth, and we will inevitably see new polymer materials developed with improved barrier and functional properties creating alternative package constructions, with a move towards more environmentally friendly options.

An example of the type of material development underway is the 'Oxbar' structure, which is an MXD6/cobalt mixture blended with PET that has been used successfully as an oxygen-scavenging total barrier system for fruit juice and wine packs.

The more traditional metal-based packaging systems will inevitably continue to develop. The Metpolam lamination process for laminating PET or PP to steel or aluminium has opened up opportunities for 'microwavable', plastic-look-alike trays and pots to be produced, offering total barrier properties plus metal forming outputs and potential benefits.

The future looks good for the food manufacturer looking for shelf-stable packaging systems. The developments in processing and in new added-value markets will further stimulate the packaging developments looking for increasingly diverse but effective packaging formats.

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Relationship between Impact Energy and Design Parameters of Glass Bottles*

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Glass containers are relatively heavy. Also, glass is fragile, and breakage sometimes occurs during handling and transport. Therefore, glass bottles must be constructed to achieve maximum strength at minimum weight (wall thickness). To our knowledge, about 85% of all breakage is caused by external impact.

The purpose of the present paper is to study the relationship between the shape and thickness of glass bottles and the impact loads they can resist by using linear multivariate statistical/mathematical regression (or calibration) techniques (UNSCRAMBLER), in order to compute minimum required thickness of the bottle as a function of impact strength and vice versa.

The study was based on 10 different types of bottles. Moreover, we have concentrated on measurements related to the heel of the bottle. The set of bottles used are described as follows: returnable, round body, straight side wall and without metal oxide coating. All the bottles were given a standard abusement before the impact tests.

The following conclusions were reached:

(i) there are strong relations between glass thickness and the resistance to external impact (as expected);

(ii) multivariate calibration gave much better results than using only one variable at a time;

(iii) the predictive ability is not good enough (accuracy of ±10–15%), but provides useful information that would be difficult to obtain by other methods.

Keywords: Glass bottle design; impact energy; multivariate regression techniques; stress distribution

INTRODUCTION

Glass containers are relatively heavy. Also, glass is fragile, and breakage sometimes occurs during handling and transport. Therefore, glass bottles must be constructed to achieve maximum strength at minimum weight (wall thickness).

Computer programs can be used to compute the required thickness of glass bottles; current techniques are based mainly on the finite element method[1,2] and give strength predictions from internal pressure loads, axial loads and thermal shock loads. Their weakness, however, is that they do not take into account how much impact energy bottles can resist before they break. This problem is serious when we know that about 85% of all breakage is the result of external impact loads.

The purpose of the present paper is to study the relationship between the shape and thickness of glass bottles and the impact loads they can resist by

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