6

GLASS CONTAINERS

D.A.Dean

Introduction

Glass is believed to have been first discovered around 3000 BC in the East Mediterranean. It has been established that hollow glassware existed in Egypt around 1500 BC and was made by the sand core method. A core or clay was attached to the end of a metal rod then coated either by dipping into molten glass or by winding threads of molten glass around it. The vessel was then reheated and made smooth by marvering, i.e. rolling on a flat surface. Even in those ancient times such containers were used for ointments, perfumes and cosmetics, but due to the restricted availability they were only used by the extremely rich. The sand core method was supplemented by the pressing of bowl shapes, until true glass blowing was invented in the first century BC. Early glass blowers were the Egyptians, Syrians and Jews based at Sidon. With the emigration of Syrians and Jews, glassworks gradually became established throughout Europe. Thus as glass expanded, so did its use for pharmaceuticals.

Glass has served the pharmaceutical and cosmetic industries as an effective container for many centuries, and particularly during the past 100 years. Some 40 years ago, with the advent of plastic containers, glass was virtually condemned as an obsolete material and a rapid decline in its use was forecast by the plastics salespersons. Since then in an expanding packaging era both glass and plastic have enjoyed a period of increasing usage, at first in direct competition with one another, but now reaching a state of association and union (in the form of plastic-coated glass bottles and glass composite packs). Also, glass would not have become such a universal container for pharmaceuticals had the plastic closure not been available.

In 1969 approximately 14% of blown glass containers were supplied to the pharmaceutical and toiletry industries (9.2% and 5% respectively); in 1971 this reduced to 11% (7.3% and 3.5% respectively), in spite of an increase in total production. The major users were the food, beverage, beer and spirit industries. Although the use of glass again dropped in the late 1980s, this trend generally reversed in the early 1990s. Part of this is attributed to the popularity of bottle banks and the belief by the general public that glass is a more ‘friendly’ material. In the same period, coatings on glass have improved the colour range options and general strength, coupled to further light weighting.

The fact that glass has been so successful for such a long period reflects not only the fact that it was discovered before other materials but also that it still meets most of the requirements of a modern packaging material. Glass is economical, can be handled at high speeds on production lines, is inert (thus giving excellent product-pack compatibility), and provides good product presentation (clarity, sparkle, design) and good product protection. Early limitations in the use of glass were associated with the production process and difficulties in finding a fully satisfactory closure system.

Glass could be defined as the original plastic material in that it closely resembles a thermoplastic. It is softened by heat, capable of being fashioned in a mould, and can be reheated and remoulded into another shape many times with little deterioration. However, glass is inorganic in origin, whereas plastics are organic.

Both the earlier glasses and today’s major usage are based on soda glass, which is a product of the fusion of sand, soda ash and limestone, hence the name soda or alkali glass.

Early uses of glass included the preservation of food. In 1805 Nicholas Appert in France showed that heat would preserve foods by arresting their natural tendency to spoil. For this he recommended glass containers closed with long corks. Usage was, however, restricted due to poor processing techniques and the variability of closures. In 1858 an American, John Landis Mason, invented a screw-topped jar which was subsequently used by housewives. Domestic food-preserving jars are frequently known as Mason jars. The cost of the closure and method of handling did not make fuller commercial usage worth while. Louis Pasteur in the 1860s explained the spoilage of foodstuffs by micro-organisms, how they could be destroyed by heat and the product preserved by the use of air-tight containers. He too used glass containers, but also had problems with the closures.

One of the first bottle-making machines, invented in 1882 by Phillip Arbogart, was based on a press and blow technique. With the development of further ideas at the beginning of the twentieth century, improved closures soon appeared. The roll-on closure was invented in 1923 and the pry-off cap in 1926. However, the cork reigned supreme for many years in both waxed and unwaxed forms. Ground glass stoppers were also very popular at one time, each bottle bearing its own stopper which had been individually ground into the neck, thus assuring a good fit. The medicine bottle, as such, probably first came into regular use as a narrow-necked glass vial for liquids.

Bottles for general use became known by their shape, i.e. rounds, ovals, panels, hexagonals and flats. Others bore special names such as Winchesters, corbyns, ampoules, vials, Mexicans and carboys.

Composition of glass and types

The exact structure of glass is not clearly known. It can be formed by mixing together various inorganic substances which on heating give a homogeneous molten mass. On cooling this does not arrange itself into crystal pattern but becomes a super-cooled liquid in which ultimately the state of flow has ceased to exist. When most liquids cool, the transition from a liquid to a solid state occurs abruptly at a specific temperature with the simultaneous evolution of heat. This freezing process depends on the formulation of crystal nuclei. However, certain liquids increase in viscosity with cooling and this hinders the formation of nuclei. Since, in the case of glass, nuclei are not formed, it remains in a super-cooled state until a solid state is reached. The properties may be varied according to the raw materials used. Sand, which is the main ingredient and consists mostly of silicon dioxide, requires very high melting temperatures (1700°C+). If certain fluxing agents such as soda ash (sodium carbonate) are added, the melting temperature reduces to around 800°C but the resulting substance, widely known as water glass (Na_2SiO_3), is soluble in water. If a stabiliser such as limestone ($CaCO_3$) is added, conventional (insoluble) glass is obtained. Normal alkali glass is basically fifteen parts sand, five parts soda ash and four parts limestone—the mixture being heated to about 1500°C. At this temperature the three ingredients gradually react. To help melting, cullet or broken glass (of the same type) is added to the basic raw materials. Early glasses had a green tinge due to the presence of iron. Today virtually colourless glass is produced by using decolourisers such as selenium or cobalt oxide. For each 10% of cullet added, energy (heat) can be reduced by approximately 2.5%.

Compared to plastics, glass additives cover fewer purposes, i.e. colourants, opacifiers, decolourisers, modifiers, and stabilisers. Certain additional technical ingredients may be employed, e.g. alumina to improve durability. Coloured glass may be obtained by solution (glass acts as a solvent for certain oxides) or by colloidal dispersion: the following are examples.

- *Amber:* May vary from light yellowish to deep reddish brown. Obtained by the addition of carbon and sulphur or iron and manganese dioxide.
- *Yellow:* Compounds of cadmium and sulphur.
- *Blue:* Various shades of blue, cobalt oxide or occasionally copper (cupric) oxide.
- *Green:* A range of greens can be achieved by varying additions of iron oxide, manganese dioxide and chromium dioxide. Actinic green is the name usually given for glass of a bright emerald green which absorbs the ultraviolet wavelength of light.
- *Opal:* Involves fluorides or phosphates.

Although most glasses are coloured in the main melt, it is possible to add the colourisers as a frit at the feeder conditioning stage prior to extrusion as gobs into the glass blowing unit. This obviously gives greater flexibility in allowing additional colours to be produced, but the resultant cullet frequently cannot be reused (coloured cullet can only be used to produce containers of the same or similar colour). Normally a glass furnace has an expected life of 8–10 years and will run most economically on one colour. Frequent changes from one colour to another can obviously cause lengthy and costly downtime—for this reason unusual colours made by a continuous batch process will be more costly to produce.

Three types of furnace are in use: regenerative, recuperative and unit melters. The last, while cheaper to install and easier to maintain, with shorter downtime on colour changes, is more expensive on fuel. Regenerative furnaces are in the majority.

Several types of container glass are generally recognised:

- type I—neutral, a boro-silicate type glass
- type II—soda glass with a surface treatment
- type III—soda glass of limited alkalinity
- NP—soda glass (non-parenteral usage) or European type IV.

Colourless white flint soda glass has the following composition range: silica (SiO_2) 59–75%, calcium oxide (CaO) 5–12%, sodium oxide (Na_2O) 12–17%, alumina (Al_2O_3) 0.5–3.0%, and possibly small quantities of ferric oxide, titanium dioxide, potassium and magnesium oxide.

Type I glass

Neutral or borosilicate type glass has the following composition range: silica (SiO_2) 66–72% alumina (Al_2O_3) 4–10%, sodium oxide (Na_2O) or potassium oxide (K_2O) 7–10%, boric oxide (B_2O_3) 9–11%, calcium oxide (CaO) 1–5%, barium oxide (BaO) 0–3.0%, and possibly small quantities of magnesium oxide, ferric oxide and titanium dioxide.

These types of glass require a higher working temperature, have a narrower working range and hence are more difficult to process (1700–1750°C). Borosilicate glasses with high boric oxide contents (over 12%) show reduced chemical resistance, and are more prone to atmospheric weathering. Type I surface treated glass is also available with certain smaller tubular containers.

Type II glass

This is a soda glass which has had the surface treated, usually by a process of sulphating or sulphuring. In the former a pellet of ammonium sulphate is dropped into each bottle before it passes passes through a heated tunnel known as the lehr. This then sublimes and coats the inside of the glass. Sulphuring usually involves sulphur dioxide being injected into the container while it is within the lehr. Evidence suggests that the ammonium sulphate process confers better resistance than sulphuring.

In all these treatments the excess surface alkalinity is neutralised by forming a coating of sodium sulphate which is soluble in water. All treated containers must therefore be washed prior to use in order to remove the soluble coating which shows a 'bloom'.

Other surface treatments

Various surface treatments are now in use for improving surface lubricity, reducing damage by impact, or giving additional decorative effects.

Surface lubricity can be improved by the use of silicone coatings (it also assists drainage from the container) and hot/cold end treatments. The latter operate at the beginning (hot end) and the end of the lehr (cold end) and can involve titanium dioxide, tin tetrachloride at the hot end and waxes, waxes in combination with polyethylene, oleic acid, polyethylene glycol, stearates, etc., at the cold end. Currently tin tetrachloride is the most popular hot end treatment being applied from bottom up or neck downwards, with the latter being more likely to give some internal contamination. These coatings generally provide greater slip in their role as lubricity coatings.

Other inorganic and organic treatments are available. In one Japanese process, surface sodium ions are replaced by surface potassium ions in the molecular structure of the glass. Organic coatings include various polymers—surlyn, polyurethene, etc., —or the direct application of plastic sleeves as shrink or stretch wraps (PVC, PP, PET, LLDPE, etc.) at the glass manufacturing site. All these processes can reduce surface damage and maintain bottle strength and/or be used to add decorative designs, colour, etc. It should be noted that coatings cannot fully replace either poor glass distributions or bad design. A more recent inorganic coating involves silica. A special finish coating is required where an induction sealed diaphragm is to be employed.

Selective coating to improve the image of glass seems assured. By such techniques and good design, Japan has already produced cylindrical containers of half the weight and twice the strength of those previously available, but at a relatively high cost.

Properties

Glass shows a high degree of chemical inertness in that hydrofluoric acid is the only substance which appreciably attacks it. Instances of surface attack which can lead to the detachment of 'flakes' are few. This can occur with type I, alkali or treated glass either after autoclaving or on long-term storage in contact with certain inorganic alkali salts such as sodium citrate, tartrate, phosphate or saline solutions. Alkali glass, as indicated by its name, can give up alkali to aqueous solutions and can therefore affect either suspended or dissolved substances. For instance, the amount of sodium extracted from 100 cm^2 of glass varies according to temperature, i.e. 5 mg extracted after approx. 6 months at 20°C or 120°C for approx. 1 h. Some of the factors which influence the degree of chemical attack on glass are:

1. chemical composition of the glass
2. temperature of attacking agent
3. time in contact
4. previous history (e.g. weathered glass is more prone to attack).

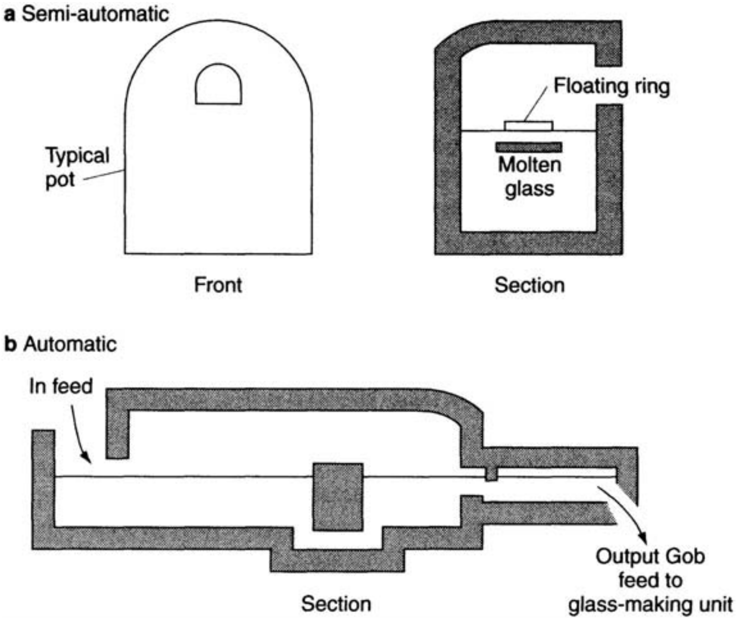


Figure 6.1 Melting tanks

Salts of sodium, potassium, calcium and magnesium can be extracted in small quantities—usually ppm (this passes EU extractive tests with reference to food contact).

In certain instances the use of neutral glass becomes essential—ordinary insulin was quoted as a prime example where pH control is critical. Neutral glass is far more resistant to chemical attack. Treated neutral glass is also available.

Glass is completely impermeable to all gases, solutions and solvents. It has a high degree of transparency when clear but can, in either amber or selected green shades, offer good resistance to the passage of UV light. Amber glass will show the greater absorbance of IR rays (see USP XXIII)

Soda glass has a density of 2.5 and borosilicate glass 2.25. Hence it is lighter than most metals. Its rigidity and ability to withstand top weight (i.e. stacking) is particularly good. The same rigidity and strength make it capable of withstanding internal as well as external pressures. Heat resistance and a high melting point make it a material suitable for both moist and dry sterilisation. Borosilicate glasses are particularly good against thermal shock. Soda glass is quite suitable for hot filling operations providing attention is paid to design, container size and the temperature difference (see thermal shock testing, pp. 231, 260) (coefficient of thermal expansion is three times greater for soda glass than for borosilicate glass).

The smoothness of a glass surface makes cleaning easy and generally restricts surface damaging, scratching or bruising to an acceptable level. The weakness of glass relates to the fact that a glass is only as strong as its skin. Surface damage (usually traced to minute fissures) can cause significant reduction in its strength which is readily shown by internal pressure testing. Strength based on bursting tests on new, delivered and used bottles have shown a ratio of 7:4:3—i.e. a steady reduction. Glass-to-glass contact or glass in contact with harder materials must therefore be minimised. If the surface of a glass can be increased in lubricity or slip, then impact damage can be reduced and its strength maintained by the use of the coatings previously mentioned. Glass is basically a strong material (20×steel) but it ends up with approx. 1% of its original theoretical strength. Glass is strong in compression but weaker in tension. Glass also presents low microbiological risk both as delivered and after storage.

Glass is therefore a rigid, inert container which will generally withstand the rigours of handling, filling, closuring and use, and if required for reuse can be easily recleaned. Its weight and stability with the right designs enables extremely high-speed processing through a plant (speeds in excess of 1000/min are achieved in the food industry). In terms of basic cost of raw materials, soda glass is relatively cheap but the energy processing cost (1500°C) is high when compared with the competitive plastics. In total energy (i.e. the energy needed to collect and convert the raw materials to a finished product), glass is favourable in comparison to other materials. However, the cost of setting up a glass blow moulding facility is very high (£30 million plus). Glass containers need an extra process known as annealing—the container is reheated to dull red heat and then cooled under controlled conditions in a lehr, whereby 'setting' strains are minimised. Annealing temperatures are around 560° C for soda glass and 580°C for borosilicate glass. Strains basically arise when the inner and outer surfaces of glass cool at different rates and the hotter surface is in compression and the colder surface in tension.

Providing a satisfactory closure rarely presents a problem if conventional practices are followed. Pourability is generally good and special screw-threaded finishes with pourer lips are available, but these add to bottle and cap costs.

With any packaging material in use today one must also consider its effect on life in terms of disposability, pollution, recycling, etc. and the possible drain on natural resources. Although the economics of total reuse present some difficulties, the partial recovery of glass remains economically viable. Broken glass (of the same type) or cullet, as it is known, considerably assists in the melting operation and is an essential part of the manufacturing process. Glass not committed for direct reuse or recycling can be satisfactorily used for land fill or other specialised purposes. At this point the obvious hazard associated with glass must be emphasised. It can be easily shattered, fractured and broken by sharp impacts, and the broken glass creates severe hazards for people or animals. Although this hazard has generally been accepted, one still has to recognise that a splinter of glass found in a product must be considered an extremely serious complaint, irrespective of how the product is likely to be used or how the glass splinter occurred. This risk is ever-present even if every apparent precaution is taken to avoid it (e.g. coated glass).

Apart from its weight and breakage feature, glass rates as a near ideal packaging material. This fact, plus it being one of the earliest materials to be used in quantity for manufacturing containers, means that any new material is invariably compared with glass, even when not in direct competition. This is borne out by a common testing procedure in the pharmaceutical industry to ‘put a control on in glass’. Another disadvantage is not a property of glass but a property of the containers which are made from it, and relates to storage. Glass containers store air and are generally more expensive than most competitive materials for warehousing. Whereas plastic containers can be made immediately prior to filling or consecutively by a form fill seal process, this type of operation is virtually impossible with glass due to the cost and the type of manufacturing processes employed.

One final feature which has caused comment is the weight of glass containers. Thus there have been consistent efforts over the past 25 years to ‘light’ or ‘right’ weight most containers. This has been achieved by combinations of design, the processing machinery, and computer-aided design and manufacture (CAD/CAM). However, not all designs can be reduced in weight and in more angular shapes this is neither practical nor critical. In fact the solid feel of the pack may be an asset. Glass is, as indicated earlier, a strong material which is readily weakened by surface damage. The advent of the extremely thin walled container with a plastic covering or skin shows that a marriage has been achieved between two apparently competitive materials.

Manufacturing processes

Glass containers can be fabricated by certain basic processes:

1 blown glassware based on either press and blow or blow and blow principles
2 tubular glassware—a tube of glass is first produced and subsequently cut and shaped (after reheating) by a separate process
3 pressed glassware—rarely used for packaging containers.

Blown glass

This can be produced on automatic or semi-automatic equipment or can be handmade. Manual blowing of containers is still used on a limited scale for specialised ware, and is not covered here.

Few bottles are now made by the semi-automatic process but it is used for limited quantities of specialised ware. As it employs a basic team of three or four persons, the work is very labour-intensive with a low output speed. A pot furnace supplies the molten glass and each team is fed by a ‘gatherer’ who is highly skilled at lifting out the right amount of glass (gob) on a metal gathering iron. This glass is allowed to gravity feed from the iron into a parison mould, the glass gob being cut with metal shears. The parison is blown to shape and then transferred to a finishing mould where it is blown into the final design. It is then taken to a lehr for annealing. Semi-automatically made containers cannot be fully light weighted. The process is otherwise similar to that used in a fully automatic blow and blow process. The cost for semi-autoware can be five to ten times greater than a similar bottle made by the fully automatic process. Automatic glass making machines are supplied from a tank furnace. These usually have a capacity of up to 300 t (1 day’s processing) and are continuously supplied with the mixed ingredients at the infeed/melting end and deliver accurately sheared gobs to the glass blowing machine at the other end (see Figure 6.1).

In the blow and blow process the gob is dropped into an open blank or parison mould. The neck is formed by top blow and then the parison or blank is blown from the base (Figure 6.2). The blank shape supported by the transfer ring is then transferred to the finishing mould where it is blown into the final shape. This blow and blow process is the major process employed—usually with IS (i.e. independent or individual section) machinery Other machines include Roirant R7, S10 and Lynch 44. IS machines may have 4, 5, 6, 8, 10 or 12 stations. For small containers double, triple or quadruple gobbing may be employed. The last can give speeds of over 400 containers per minute.

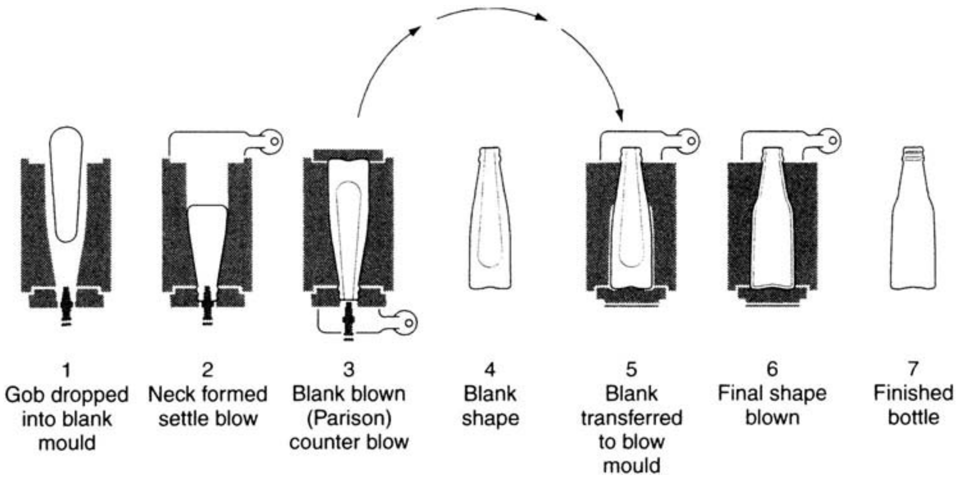


Figure 6.2 The blow and blow process (bottles)

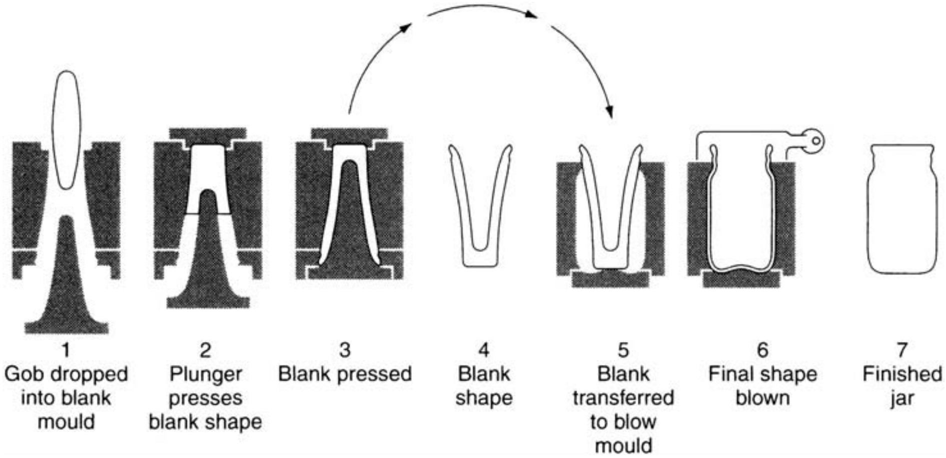


Figure 6.3 The press and blow process (jars)

Alternatively a press and blow process may be used for wide-mouthed (and now certain narrow-necked) containers. The first stage is a gob feed into a mould which is followed by a plunger descending or ascending to form both the neck finish (at end) and the parison shape. As in the blow and blow process, the blank is then transferred to a finishing mould where it is blown into the final shape (Figure 6.3).

Press and blow processes have recently found new applications for narrow-necked containers resulting in up to 25% further light weighting on cylindrical containers, i.e. pharmaceutical 100 ml cylindrical rounds (90+ g reduced to less than 70 g).

Pressed glassware involves only the first stage of the above process, the final shape being achieved by one pressing of the glass which is entrapped and shaped between the mould walls and the plunger. All automatic glass producing processes operate around the clock, for approximately 360 days per year.

Borosilicate type glasses are more difficult to produce on conventional glass making equipment (than soda glass), because they are inherently tougher and have both a high working temperature and a narrowed working temperature range, hence production rates are lower with higher rejection levels. This further increases the container cost as base material is already higher than soda glass, and is the main reason why larger neutral glass containers are not more widely used. Treated glass containers (type II) form an economical substitute.

Annealing

All glass containers pass through an annealing lehr prior to final inspection.

Sorting and inspection

As glassware emerges from the lehr, hand or automatic sorting is required. The latter is widely used for pharmaceutical containers. To carry out automatic sorting operations the containers are marshalled onto a single line conveyor, for electronic or mechanical checking for body dimensions, bore, visual damage (i.e. using imaging techniques), etc., prior to final packing. In other circumstances normal sampling procedures are applied for laboratory QC checks, plus hand inspection of each container prior to packing. The sorting area is usually screened from the dirtier manufacturing process, and is under positive air pressure in order to assist cleanliness.

Outer packaging

Glass containers were supplied for many years in open returnable wooden crates. Current means are:

1 fibre board outers
2 baler bags (now in limited use)
3 shrink wraps (palletised).

Fibreboard outers/baler bags/shrunk wraps

Both solid and corrugated board are used, but the latter is more common. An outer provides for:

1 a means of handling, identification and transportation
2 storage of empty bottles and maintaining them in a clean state
3 protection against journey hazards
4 suitable unloading onto a production line.

For handling and stacking, a brick shape giving a ratio of 3:1.5:1 is ideal. H tape or single strip sealing is usually applied to the top case flaps to exclude dirt and dust. The base flaps are less firmly closed, as it is often necessary to deposit the containers at the beginning of a production line by opening the base flaps. The bottles are usually inverted in the outers.

However, fibreboard has been criticised because of loose fibres. Baler bags received favourable publicity a few years ago but found rather limited use against the more competitive shrink wrapping systems. Shrink wraps as sleeves or overwraps may be used around complete pallet loads or small unit quantities. In the case of wrapped pallet loads the bottles may be separated with layer pads. On smaller quantities, bottles may be trayed or left without additional support (i.e. direct shrink wrap). Again the pallet may have a full shrink wrap to give added security and protection, and this is now the preferred method of packing.

Tubular glassware

‘Cane’ for tubular glassware may be made by one of two processes—Danner and Vello. Danner was the earlier process but is not detailed here, since it has been largely replaced by the faster Vello system. Both can produce ‘cane’ in soda or neutral glass.

Vello process

Glass flows from a forehearth into a bowl or reservoir in which a hollow bell-shaped mandrel rotates in a ring which allows the glass to flow via the annular space to give a continuously emerging tube. Blowing air is fed via the end of the bell where there is a hollow tip. The dimensions of the tubing are controlled by the glass temperature, the rate of draw, the clearance between the bell and the ring, rate of draw-off, and the pressure of the blowing air.

During the process the tubing is gauged, classified for use, and cut into lengths. In subsequent production the tubing may be used in a horizontal or vertical plane. The latter is currently more popular.

Containers are made by flame cutting the tube to length, flaming and shaping each end. The containers are subsequently annealed.

Due to these processes producing greater control on the side wall thickness, tubular glass containers can be made with very thin sections and of a much lighter weight than blown glass ware. Ampoules, vials, cartridge tubes and prefilled syringes all indicate the capabilities of the tubular process. In their initial use ampoules were followed by vials, originally for oral products (tablets) and then for multidose injections (Figure 6.4).

More recently glass disposable and prefilled syringes, mix-o-vials, etc. have extended the use of tubular glass. In general neutral glass is more widely used. This can be twice the price of soda glass but annealing is less critical, although still essential.

The physical cutting of tubular glass gives rise to glass particles, which also occur when any type of glass ampoule is opened. In the case of glass particle contamination in containers made from tubular glass there are various methods for reduction or elimination, i.e. high-pressure air blowing, high-pressure water washing, each with or without ultrasonics, and heating to dull red heat (during annealing) to fuse the glass fragments to the walls of the container.

Tubular glass containers are made in neutral type I, surface treated type I glass, soda glass, etc., and may also be siliconised as a separate process after manufacture. Surface treated type I glass is occasionally necessary in smaller containers, where now and then a sample fails the neutral glass test.

Design and decoration

The design of any container involves two basic considerations—aesthetic appeal and functional efficiency. With an established type of product, designs either follow tradition or endeavour to break from it in the hope that a new association can be created. Size impression frequently dictates design limitations such as a big looker, bigger than *x* approach. So often the requirements of appeal and functional efficiency are conflicting in the extreme. Functional efficiency can be applied to many aspects, i.e. delivery to factory, production line (stability, handling speed), closuring, packing, warehousing, and finally stability at point of sale and consumer convenience. If taken to the extreme, the basic alternatives appear to be round or square sectioned containers, the former for general ease of handling and strength and the latter for the maximising of space. The compromise is a square or rectangular bottle with well radiused edges, an in sweep at the base, and an even taper from the body to the neck finish, e.g. a modern rectangular tablet bottle. The relative strength of various shapes is of the following order: circular 10, oval 5, square with radiused corners 2.5, square with sharp corners 1. Thinning, which may occur in a square-cornered container, is indicated in Figure 6.5.

From these general observations one can identify basic guidelines.

As glass is weakened by surface damage, designs which lead to point to point contact (Figure 6.6) are particularly susceptible to damage if handled on conveyor belts. If the areas of contact can be spread over greater areas there is less risk of damage (Figure 6.7). Designs must also aim at providing a uniform wall section and avoiding thick and thin areas which offer points of weakness in use and areas of extra strain through cooling differentials. Even distribution depends on the design of both the final shape and the parison mould.

Square sections should be avoided whenever possible. This can be achieved by con sideration of a suitable radius—see Figure 6.5. At the base of the bottle one has to reach a compromise between maximum stability (a broad wide base with near square edges) or optimum glass distribution with a ‘drawn in foot’ which naturally reduces the total base area.

Stippling of the base is useful in improving base grip, masking mould scars and improving the strength of the container. Damage to individual stipples does not normally lead to surface weakening as the strength (and surface which may be weakened by damage) lies in the plane at the base of the stipples. Similarly, the neck of the bottle should avoid sharp changes in direction, preferably utilising gradual slopes and incorporating adequate radii.

The ability for a neck to accept a vertical load is shown in Figure 6.8. High stacking strength is a recognised feature with glass.

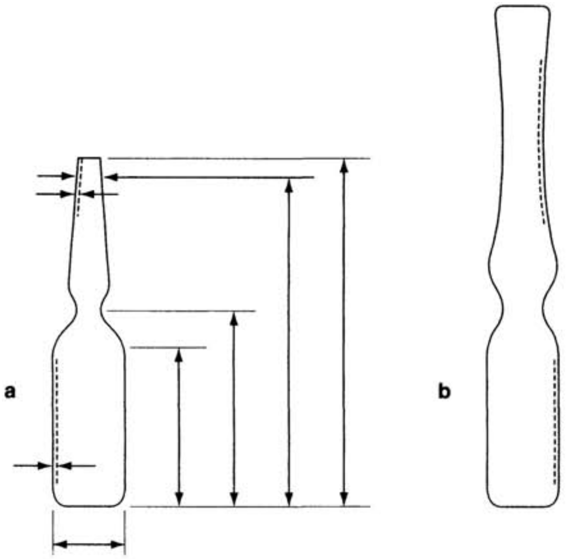
Large flat surfaces should be avoided as these tend to sink during the cooling of the glass and may give rise to labelling and capacity problems. A large radius should therefore be used, as exemplified by Figure 6.9.

A bottle must be designed to be removed from or clear the mould. This can be illustrated by taking a bottle of rectangular section as shown in Figure 6.10. It is apparent that the mould fouls the edges A and B as it opens. In this case the bottle manufacturer will arrange the mould as shown in (c), where the part lines are diagonally across the bottle. While this would produce a satisfactory bottle, it is better avoided as adjacent parts of the mould are not symmetrical, and can lead to uneven mould wear. This problem could be overcome with the rectangular shape by radiusing the ends of the bottle as shown in (d) where a symmetrical mould can be used.

In a more complicated bottle as in Figure 6.11, neither a diagonal part line nor an asymmetrical shape is avoidable.

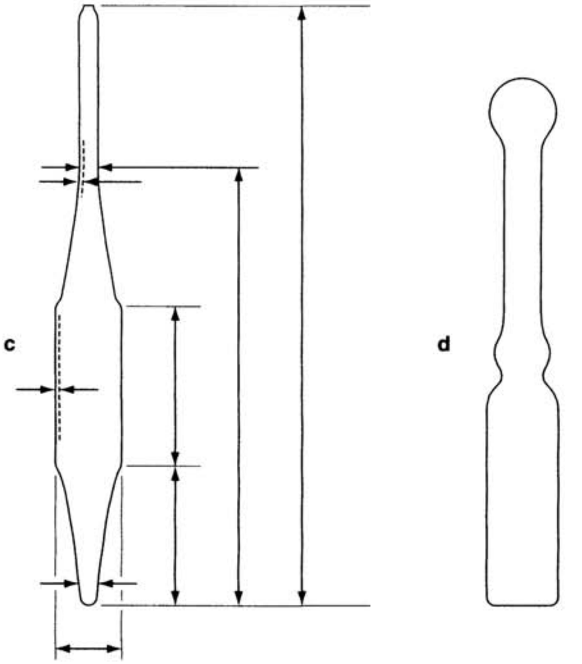
Embossing of a bottle, such as that employed on intravenous solution containers, can induce stretch lines, but the correct use of radii can minimise the problem (which tends to be visual rather than a point of mechanical weakness). The height of the embossing should be kept at a minimum—usually around 0.4–0.75 mm. This feature of the bottle clearing the mould can easily be overlooked and however good a design is, it fails if the bottle cannot be made! Bottles may also have debossed areas, e.g. to take a hanging harness.

Examples of improving a design are given in Figure 6.12, which shows an old and an updated Winchester. Not only has strength been increased and light weighting achieved, but pourability has been improved (by lessening the risk of air entrapment when tilted).



Flat bottom, narrow stem
Cut ampoule with constriction

Flat bottom
Stem with constriction



Double pointed ampoule

Presealed ampoule

Figure 6.4 Ampoules

Panels inevitably cause glass distribution problems, and Figure 6.13 indicates steps taken to modernise a typical panelled pharmaceutical bottle.

A Original bottle—note angular base, long narrow neck.
B Improved shoulder—wider and stronger neck section.
C Removal of panel: maintain parallel sides, draw in base-neck. Design now follows total shape better, front panel convex—eliminates sinkage risk and makes for better labelling. Finally bottle weight reduced and glass distribution maintained—stronger bottle. This final bottle also offers advantages in faster filling and better pouring.

Toilet bottles give more scope for the imagination, but the same rules of good practice should be applied when possible. Occasionally, rules may have to be relaxed as in many instances special shapes are said to be ‘essential’ and light weighting

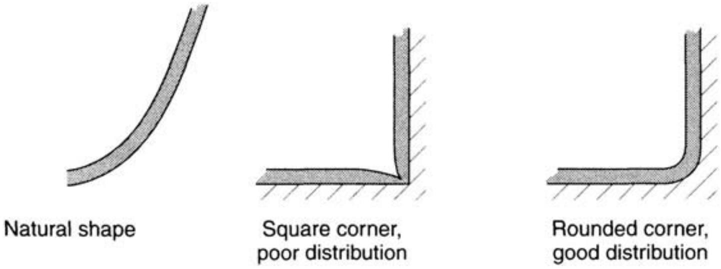


Figure 6.5 Glass distribution

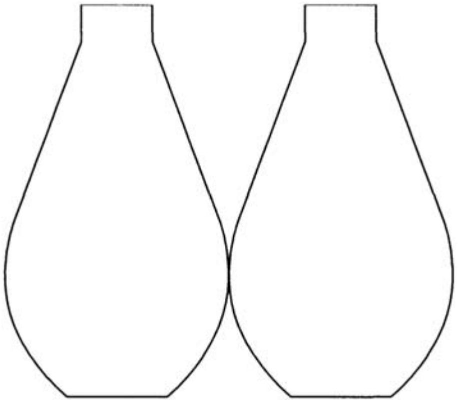


Figure 6.6 Avoid point to point contact

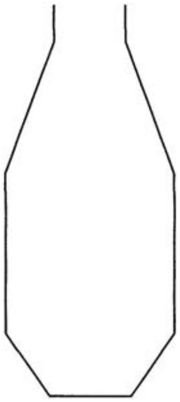


Figure 6.7 Good contact area

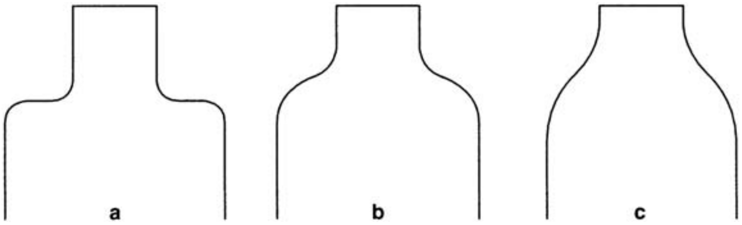


Figure 6.8 Neck/shoulder design: capable of accepting vertical load of (a) 500 lb/in^2, (b) 4,000 lb/in^2, (c) 10,000 lb/in^2

and high-speed filling may be of less importance. While a square edge is still not good practice, this may be disguised by a double radius. A bevel may be improved by superimposing a series of fine flutes (see Figure 6.14).

It is frequently necessary to design a family series, and as a general rule a 25% increase of the original shape in height, depth and width will double the capacity. One final trick with any design is to turn it upside down—it may look much better that way (Figure 6.15). The use of CAD/CAM and computer technology generally is now widely applied to glass design, thus providing a faster service and improved design. 3D models can also be screened.

It should be noted that like plastic, glass has a shrinkage factor—usually 0.3% (which is less than for plastics). Moulds are therefore slightly larger than the item produced.

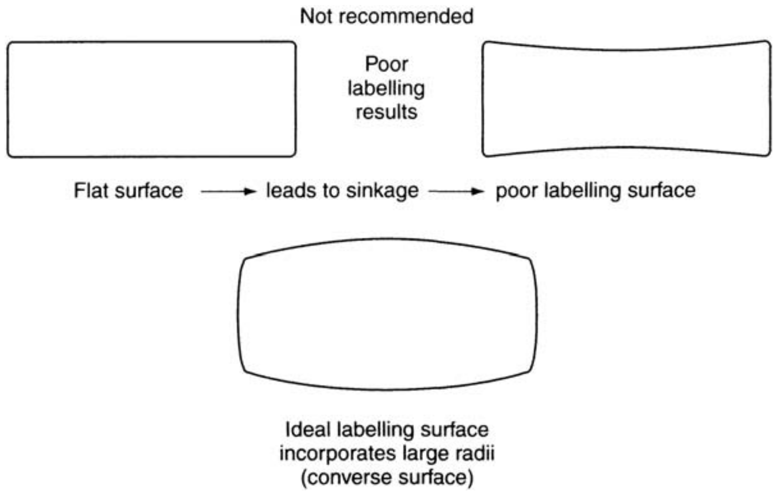
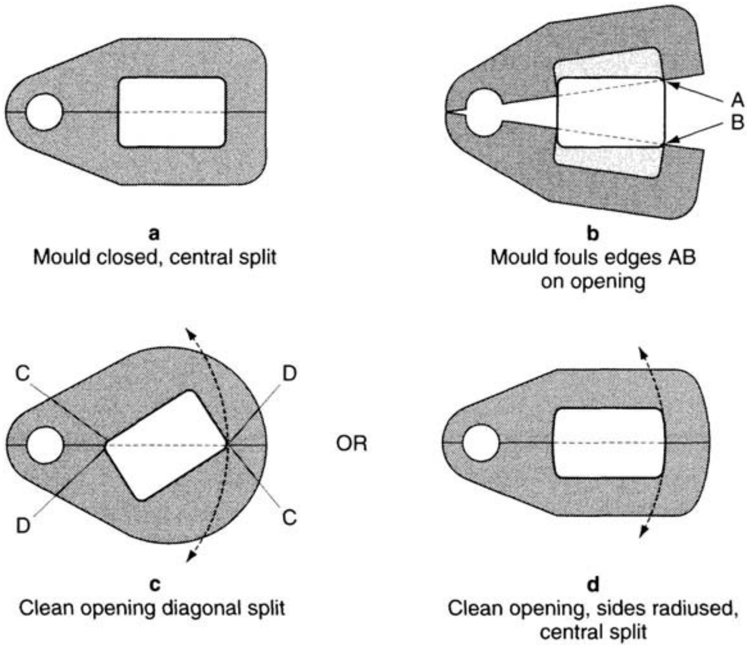


Figure 6.9 Labelling surfaces



a
Mould closed, central split

b
Mould fouls edges AB on opening

c
Clean opening diagonal split

d
Clean opening, sides radiused, central split

Figure 6.10 Design of bottle to clear a mould

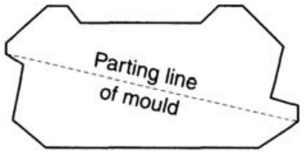


Figure 6.11 Asymmetrical design: diagonal split essential

Insufficient study of the design related to the mould can lead to bottle distortion while it is still at the 'red' heat stage. This aspect must be considered a function of the glass manufacturer and the mould maker.

Lastly, designs cannot be separated from closures—the total effect therefore must be a major consideration (Figure 6.16).

To evaluate the functional aspect of design one should first outline various points which require consideration. These may be listed as follows.

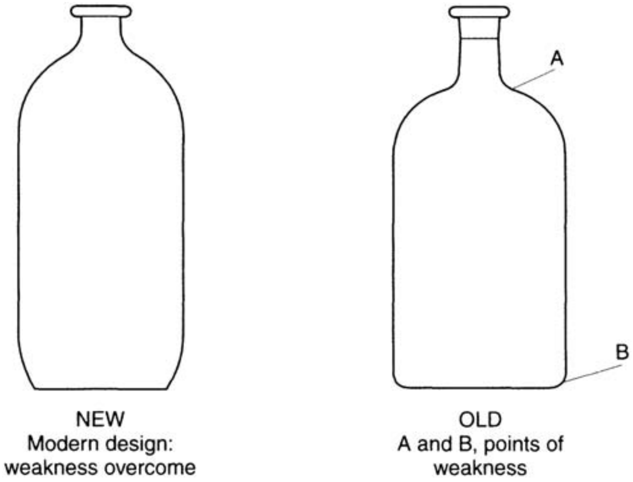


Figure 6.12 Design improvements

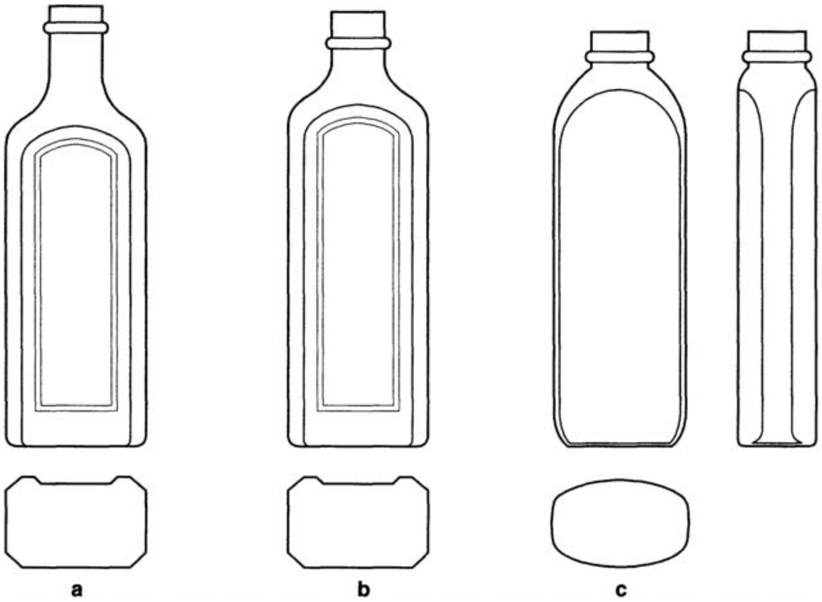


Figure 6.13 Design improvements

Production line handling

This comprises unscrambling, cleaning, filling, capping, labelling, etc. For instance, the air blowing of containers with square shoulders and narrow necks may present difficulties, and figure eight shapes create swirl patterns.

Filling speeds relate to both the container shape and the neck diameter. If conveyor feeding is likely to lead to excessive surface impacts then alternative methods of feeding may become essential, e.g. worm or screw feed (scroll). Capping speed and efficiency depend on gripping the container, the design of the neck finish and the design of the closure.

Labelling also depends on holding the container, the shape of the label, the evenness of the surface to which it is applied and the type of labelling process. A convex surface is preferred to a flat or concave surface. Excessive fall away can lead to creased labels.

Strength

This depends on design, glass weight, and glass distribution. A badly designed container can lead to excessive weighting to reduce the zones of thin areas. Note that strength bears a relationship to handling, processing and stacking.

Use of double radius to disguise square edge

A bevel broken up by fine flutes

Figure 6.14 Design improvements

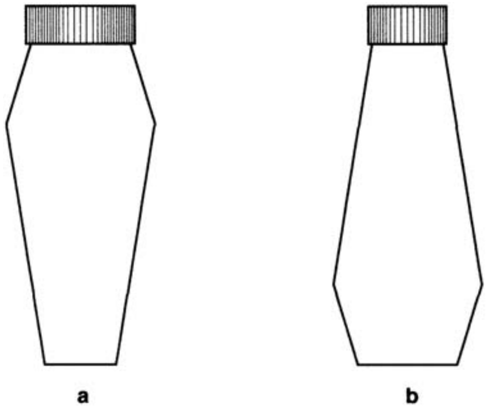
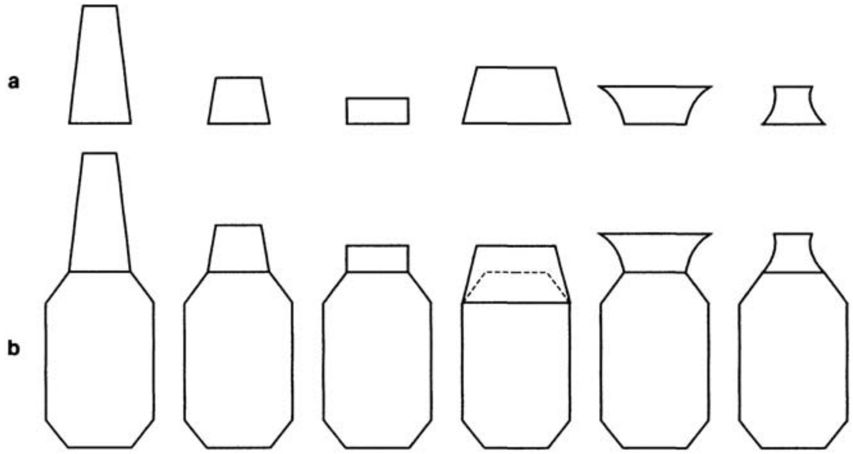


Figure 6.15 Design impression



A design consists of a bottle with a cap

Figure 6.16 (a) Closure shapes; (b) closure plus bottle

Consumer convenience

Does it rest comfortably in the hand? Are the hands likely to be wet, as they frequently are in the bathroom and kitchen? Can the cap be easily removed? Can it then be poured without changing the grip? Does it pour well? Can pouring be controlled? Where will the container be stored? (If in a bathroom, then good stability is essential.) A bottle which falls over is a danger to the user and may damage the bath or sink onto which it falls.

Display stability

Are there restrictions on display height or arrangements? Is it necessary for the pack to be self-stacking, i.e. for the base of one container to fit neatly into the top of the closure of the container beneath it?

Display potential

What is the pack competing with? What is the predominant issue—size impression, stability, confidence in handling by salesman or user(!) or appearance? How important is the label area compared with product visibility? Can a decorative process be employed rather than labelling?

Reuse

This may refer to a reclosable pack after use by the user, or multi-trip. Can it readily be rewashed, both internally, and externally, and can the label(s) be removed?

Capacity

This may be based on product sold by weight, volume, or number. Container capacity is a critical feature bearing relationships with product filling speed, the declared contents and headspace (vacuity or ullage). The ullage (airspace above product) must be adequate to allow for the thermal expansion of the product. This is particularly important with alcohol-based products in narrow necked containers. The capacity usually relates to either a brimful capacity or a defined fill point.

There is also the visual aspect of the point of fill which may, in certain designs, lead to the appearance of a low fill. Powder or granular products which settle require consideration at the design stage, the settling effect being exaggerated in narrow containers or containers with long narrow necks. Container capacity tolerances increase with size, e.g. 30±0.5 ml and 650±12.5 ml.

Costs

Bottle mould costs are likely to be of the order of £3,000 ($4,500) per mould set (i.e. around £30,000 for a ten-station IS machine).

Recyclability

All glass is recyclable, but borosilicate or soda glass must be segregated. In addition to the above functional issues it is essential that a designer receives a full marketing brief before commencing a design, covering:

- full knowledge of the product—nature, how, when, where it is used, etc.
- full knowledge of the market—is it new, what is the competition, where will it be sold?
- the content requirement (see Capacity above)
- full knowledge of any price or production restrictions which may be applied
- knowledge of the distribution system to be employed
- knowledge of legislation.

Added to this are the aesthetic issues of design, frequently requested as being better than or different from a particular product. A container should ultimately provide an economical basis for a balance between presentation, identification, protection and convenience. Models of new designs for bottles, closures, etc. can be produced either in wood or opaque or clear plastic, bearing in mind that a clear plastic model frequently looks better than the final glass bottle.

Design protection—registration and patents

Depending on legal aspects bottle shapes can be design registered but not patented unless they involve specialised features such as new innovations involving closures.

Legislation

In the USA the regulatory body for legislation associated with drug and cosmetic products is the FDA. The Food Additives Amendment to the Federal Food, Drug and Cosmetic Act places a requirement on the manufacturer to submit data on packaging materials and components to the FDA prior to marketing of pharmaceutical (and food) products. The same applies for pharmaceuticals under EU legislation. Submission for clearance of product/pack must include data on all packaging material constituents (i.e. glass type) and adequate toxicological studies to prove these constituents innocuous if not previously cleared (e.g. with plastics).

The Fair Packaging and Labelling Act 1966 also has widespread impact and is regulated by the FDA for drug and cosmetic products. The Act not only legislates against deceptive package (usually associated with packaging design and construction) but also details minimum label area size and a minimum size (height) of letters. Exemptions are included for small drug, cosmetic and toiletry containers. Additional legislation on ethical or prescription drugs is given in Section 507 (e) (i) of the Food, Drug and Cosmetic

Act. OTC drug products must prominently carry the established or proprietary name on the principal panel and must also carry a statement on the general pharmacological category.

In the UK legislation is similar to the USA involving various Acts of Parliament, e.g. Trade Description Act, Food Labelling Act, Weights and Measures Act. The last is covered by the ‘Model State Packaging and Labelling Regulation’ first adopted in 1952 within the USA.

One other Act, the Poison Prevention Packaging Act 1970, is now having wide influence on child-resistant safety packaging and is dealt with separately in Chapter 11.

Glass has been cleared by the FDA for a wide range of products. Closures present few difficulties.

Decoration

Certain decorative processes other than the more conventional labelling may be used. Some of the most brilliant effects may be achieved by ceramic printing. This is a screen process which applies pigments and powdered glass in a carrier of waxes or oils. After application the ink is ‘fired’ on by passing through a lehr at 900–1100°C, whereby the carriers are burnt away and the pigment—glass mixture melts and becomes affixed to the container. The result is a near permanent decoration which will withstand heat, cold, abrasion, etc. The texture can be high gloss, matt, satin, or rough.

Another process is the Thermo-Cal system in which ceramic decalcomanias are released from a carrying paper on to a preheated container and then fired.

Organic coatings and inks have been developed which will adhere to glass at lower temperatures, i.e. 450–500°C. These organics could be more economical than ceramics and offer a wide range of colours but are less scuff-resistant. Inorganic metallic oxide coatings may also be employed, particularly for coloured iridescence (i.e. Spectrasheen—Owen, Illinois).

Although the decorative processes apply certain restrictions (particularly half tones), the overall possibilities are gradually extending when cost is not a prime factor. In addition to paper labelling and those mentioned above are plastic labels, or tapes, close fitting sleeves (shrink or stretch) or cards, plastic fitments and plastisol dip coatings (as used for aerosols). Thus a glass pack may reach its final objective by a combination with other materials such as paper and plastic or decorative processes. New coating technologies (organic and inorganic) can provide both coloured and protective coatings, with the latter reducing surface damage which could weaken a container. More recent coatings have included Surlyn and SBR (styrene butadiene rubber) with polyurethane.

Quality control and quality assurance

QC or QA is essential to the maintenance of quality by the regular checking of parameters that will:

1 lower the aesthetic appearance and therefore give rise to adverse consumer reaction, loss of sales, etc.
2 reduce the functional characteristics—pouring, standing, opening, reclosing—and the protection of the product
3 increase the cost by increasing wastage and/or reducing output on the user’s production line.

These parameters should be directly or indirectly covered in a specification which represents a negotiated agreement between a supplier and the using company.

QC and QA as a means of measuring and controlling quality can be applied to both the glass producer’s input and output, i.e. from raw materials to finished product. They are therefore a production aid and a user’s guarantee. QC must only check those parameters which are critical or essential—the unnecessary measuring of non-critical aspects only adds extra processing cost. For instance, if the burst strength of a bottle is either directly or indirectly related to its performance, then measure it—if not, it may be of interest but not of practical importance, hence do not check it.

Two fault categories are associated with quality control—variables and attributes. Variables are those faults that can be measured, usually instrumentally, i.e. dimensional measurements, burst strength, etc. Attributes are those faults which either cannot be accurately assessed (frequently associated with appearance, i.e. visual defects) or can be assessed by go—no go procedures without resorting to accurate measurements.

It must also be pointed out that the basic materials from which glass is made have to be subjected to QC in order to ensure consistency between batches of glass and the processing of the materials. As the majority of glass containers are produced in a continuous process, this aspect is particularly important, e.g. control of colour.

Modern QC is based on recognised statistical programmes. The parameters to be controlled vary with the consumer's requirements. For instance, pressurised products must have a high resistance to internal pressure, while containers to be hot filled or sterilised require good thermal shock resistance. Possible defects have first to be recognised, classified and in some cases further defined by limit samples, i.e. a sample showing a defect to the agreed degree is acceptable; beyond this point it is unacceptable and therefore a defective sample.

The importance of recognising those aspects which are critical to a container, its subsequent processing and sale is one of experience and proper consultation between manufacturers of the packaging materials, packaging machinery suppliers, the user, etc. Being an old established industry, glass reject terminology tends to be advanced and complex (see appendices).

Prior to launch, a provisional specification should be tentatively agreed and then subsequently verified in the light of actual experience. Acceptable sampling schemes are now applied by most producers working to an AQL (acceptable quality level) agreed between producer and user. The AQL defines the acceptable proportion of detectives per batch. Further goods receipt QC schemes may be applied by a user, which means that all supplies are subjected to a second QC check. Under such circumstances it is advisable that the acceptance sampling schemes are clearly defined so that agreement on acceptance and rejection is reached with the minimum of friction. Alternatively, a user may either request a batch sample from the producer or accept deliveries on warranty without further major QC checks, for example as follows.

A batch sample consists of an agreed number of units taken throughout a production run. These are sent to the user with special identifications, but without prior checking or sorting. The user then applies its normal QC checks to these samples only. This offers some advantages in that samples are received from the whole production run and the user is not faced with the sampling difficulties associated with stacked and palletised components. As all opened stock has to be resealed, this not only is labourconsuming but also unnecessarily exposes stock to additional handling and atmospheric contamination.

Buying under warranty/certificate usually implies that the supplier and user have discussed and accepted the level of QC and QA carried out by the supplier. However, as all schemes involve risk, it must be recognised that occasionally a delivery or part delivery below the agreed standards may be received. This risk may mean that faulty bottles are found when they reach the production line or that some defectives will go undetected. (Note that even a second QC check does not guarantee that a defective batch will be found.) A scheme placing total dependence on the supplier is a practical proposition but requires a high level of confidence and understanding between the two parties. This can only be achieved by an effective and continuous interchange of information thus ensuring a proper basis for each to understand and acknowledge the other's problems, requirements and limitations.

The success of obtaining consistent supplies must therefore be met by effective QA/QC schemes and specification. The main feature of a specification should include a clearly defined dimensional drawing covering profile, side elevation and plan together with glass mass, volume and finish details. The written specification will also show accepted container name, stock and/or computer code number, AQLs, including performance tests and mode of delivery. The last is particularly important as it includes the method of packing which should be designed to meet the user's handling requirements on the production line, i.e. is it designed for efficient hand or mechanical? A specimen specification is detailed in Appendix 6.3.

As part of AQLs one must understand a number of terms and their technical meanings. Individual faults must be defined as critical, major, minor, with each group being controlled to an acceptable AQL. For instance, the AQL for a critical fault is usually nil and the discovery of a critical fault will cause either a rejection of the delivery or, if found at the glass producer's, a complete resort of the batch. A single example of a critical fault would be a bird cage or bird swing (Figure 6.17) as this would risk broken glass in a container reaching a consumer. It is fair to say that instances of bird cages or bird swings are now rare.

Critical, major and minor defects may be defined as follows:

- *critical*—type of defect which renders a bottle unsuitable for use and frequently implies a risk of personal injury; AQL usually 0
- *major*—defects which reduce usability or saleability; AQL usually 0.65–1.5
- *minor*—other defects, undesirable but accepted to a certain level; AQL usually 4.0–6.5.

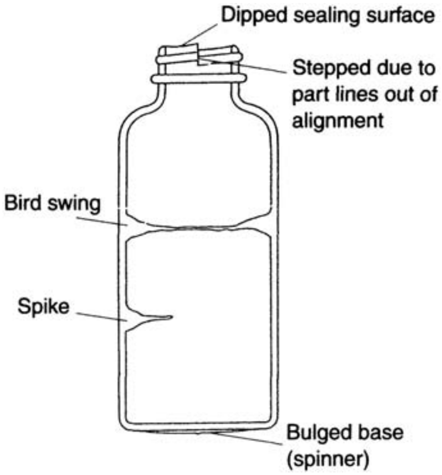


Figure 6.17 Bottle defects

The figures given are typical ones, which can vary according to the product.

QC sampling

Acceptance sampling schemes are based on the Dodge and Romig tables, Military standard 105E or BS 6001. Single or double sampling may be employed.

Tolerances—no manufacturer of glass containers produces bottles with identical physical characteristics, therefore recognised tolerances are part of any manufacturing process. The probability for the chosen tolerances is usually 0.998, thus 998 containers out of every 1000 should be within the specified tolerances. Some tolerances are interrelated, i.e. capacity, glass mass, and dimensions. If certain dimensions are particularly critical to a production line, pregauging may be carried out by either the glass manufacturer or the user on its production line prior to filling.

Dimensions may be measured automatically by either gauges or instruments. Typical gauges are shown in Figure 6.18 and are detailed in Appendix 6.1. Glass defect terminology is given in Appendix 6.2. Appendix 6.3 gives a typical bottle specification.

Bottles and production lines

Glass bottles offer advantages on weight, stability, and rigidity on production lines. Most designs can be handled on normal conveyor systems. Where the design gives a high centre of gravity, has limited contact points (for impact damage), is asymmetrical or an unusual shape it may be necessary to create a specially designed production line, or resort to individual handling (i.e. use of pucks).

Unscrambling tables must be designed to limit impact and rubbing of surfaces which weaken the glass by surface damage. Similar care must be taken with manual handling. Many lines feed via star wheels, which must be correctly shaped, positioned and sized to accept the bottle at the right point with the full tolerances of the specification.

Glass bottles may contain a variety of products, liquids, solids or gases (aerosols). The mode of filling therefore depends on the item being filled. However, prior to filling a container must be clean. Years ago all containers were washed, but other than sterile products and treated glass most bottles are usually inverted and air blown. To be effective air blowing must use dry oil-free air and have proper facilities for controlled removal of blown out debris (i.e. by vacuum).

Tests under controlled conditions have shown that the cleanliness of blown bottles can be equal to or better than that of traditionally washed bottles in terms of both fibres and bacterial count. One reason for this is the fact that bottle washing is not usually carried out in line with the filling operation, but usually a few days previously. The accumulated stock therefore has a further chance to collect dirt and bacteriological contamination unless stored under special clean conditions. When bottles exit the lehr they are sterile due to the high temperature of the process. If these receive the minimum handling under relatively clean conditions and are then either packed in fully sealed fibreboard cartons or effectively closed with shrink wraps, a low level of microbiological and dirt/dust contamination is preserved. This may seem obvious now but one must remember that traditional open wooden crates were stored under poor conditions, frequently in the open, and encouraged dirt, dust, condensation and surface corrosion. Full washing was then essential. Type II and treated neutral glass must always be washed to remove the soluble surface film of sodium sulphate.

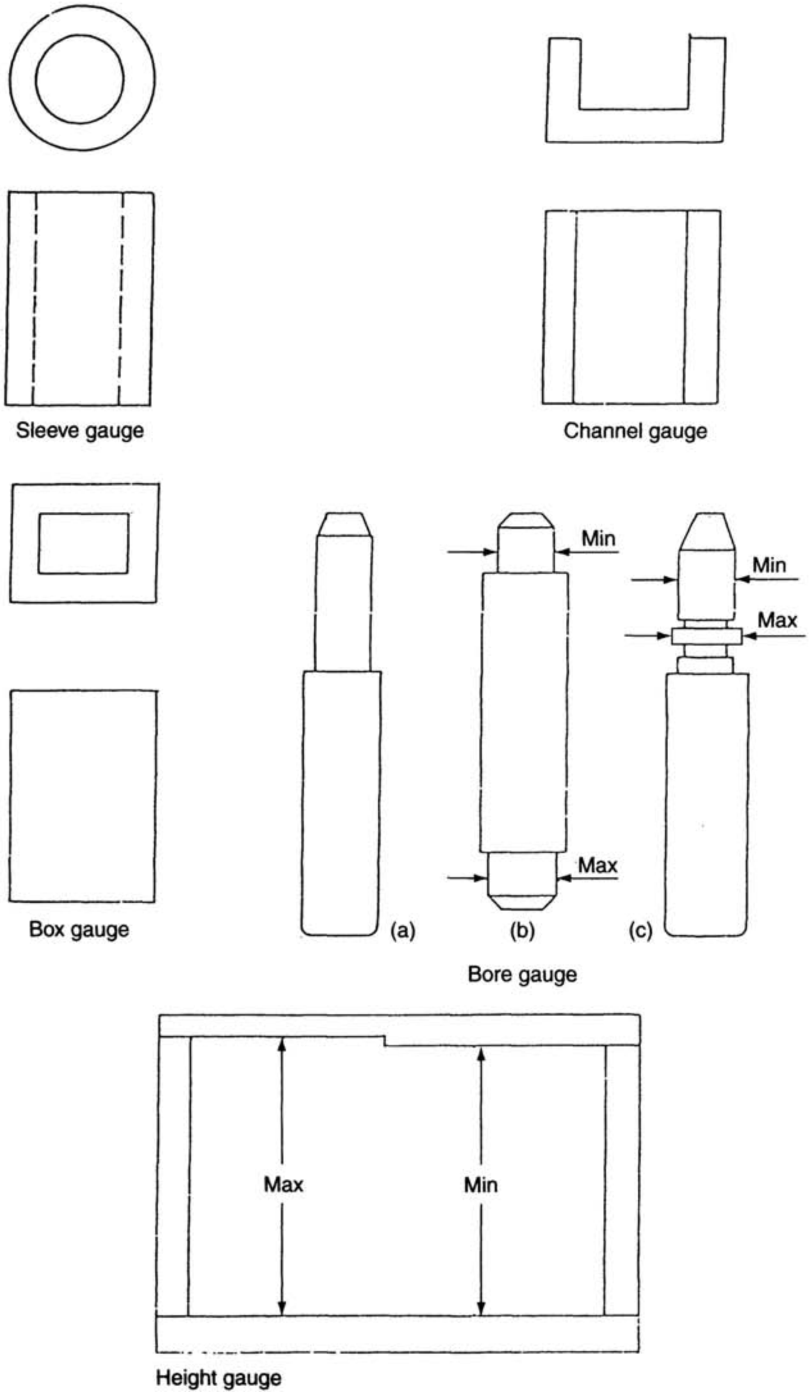


Figure 6.18 Gauge types

Filling

Filling speeds depend not only on the item and quantity being filled but invariably on the aperture of the container. Although wider mouthed containers are easier to fill, an effective closure is slightly more difficult to achieve. Some comparison between types of closure and container diameter are given later. Items to be filled include liquids of varying viscosities, solid items—tablets, capsules, powders, etc.—and gascontaining products such as aerosols. Filling can be carried out by count, volume or weight.

Count may be achieved electronically (breaking a beam of light) or mechanically by counting devices such as slat, revolving disc, column fillers, or lever trip. Volumetric fillers may be the piston principle coupled with non-returnable valves whereby the product is drawn into a cylinder and then ejected via a filling nozzle. Alternatively, gravimetric volume fillers

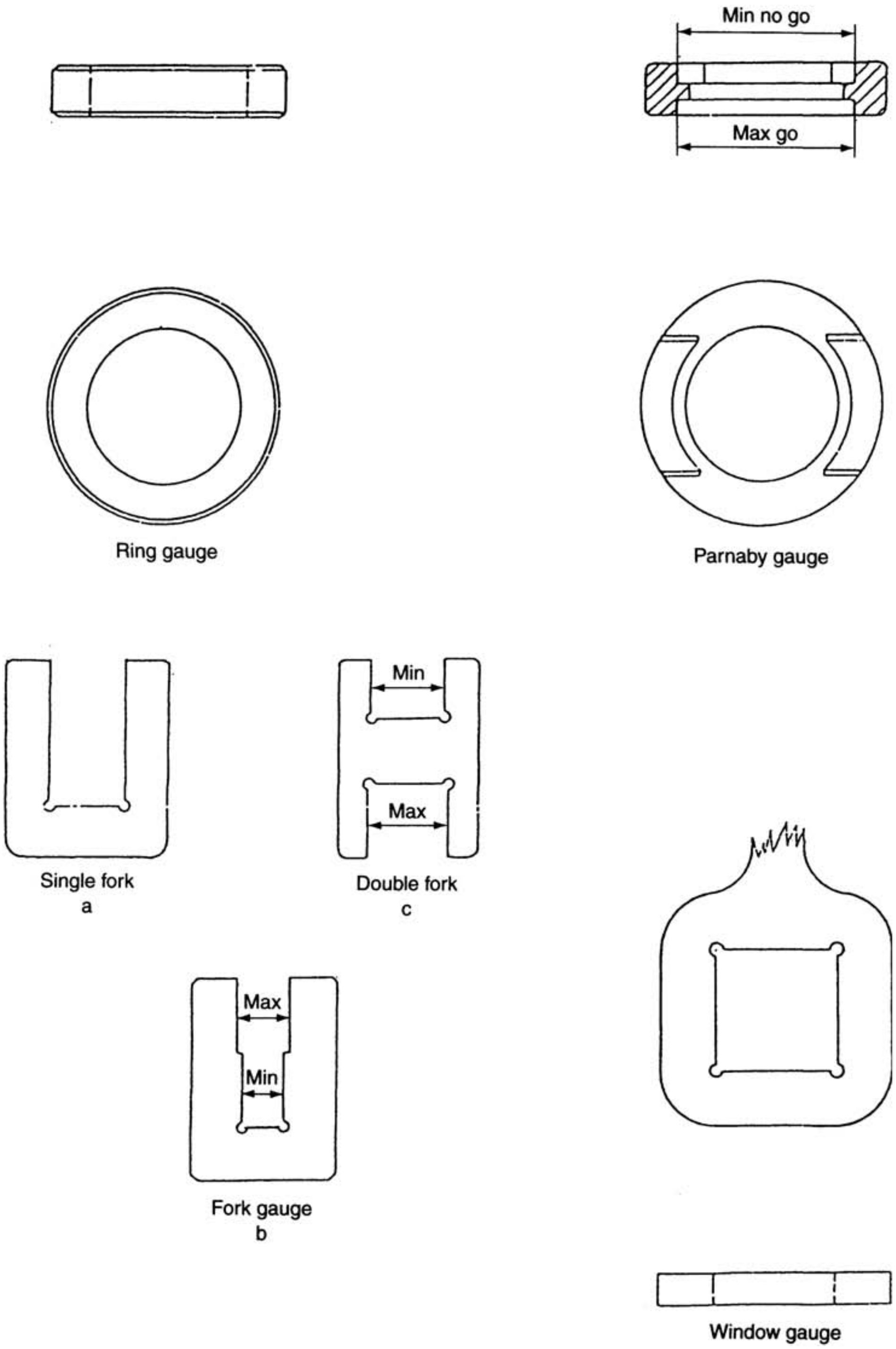


Figure 6.18 Gauge types (cont.)

may be employed in which cylinders are filled to brimful or to a defined fill level (with overflow), then a base valve opens and empties under gravity, or gravity with positive pressure assistance. Volumetric filling can also be combined with a weight feed whereby the greater part is delivered by volume with a trickle feed weight top-up to give the final requirement.

An auger screw for powders or very viscous materials is another means of volumetric filling and relies on a number of whole turns or part turns of the screw. Weight fillers can be based on a bulk weighing plus a trickle feed fill-up.

Filling to a predetermined distance either from the container base or from the container sealing surface can be employed for both liquids and powders. Vacuum or negative pressure filling is widely used. Two tubes, a filling and vacuum tube, pass through a resilient disc which makes a seal with the container sealing surface. The vacuum tube determines the height of fill by acting as an overflow system, which can be taken off in a vacuum trap. The vacuum filling system may be assisted by pressure. With liquids which froth, a tendency aggravated by vacuum, the containers may be filled by positioning the filling tube at the base of the container and then raising it to the final point of fill at the same rate as the product is delivered.

By whatever means a fill is achieved the critical factors are cleanliness of fill, accuracy and guarantee of declared content with a minimum overage. For particularly vis cous liquid products or under special circumstances, hot fills may be used. Hot fills are useful where a partial vacuum is required in the closed pack.

Placing inserts into glass bottles, e.g. pouring devices or plugs usually made of LD polyethylene, may call for a more accurate bore control than is provided by normal commercial processes. In the pharmaceutical industry, cotton wool in tablet packs, if not pre-dried, can add moisture to the product and small strands which bridge the sealing surface can act as a wick (wicking).

With a moisture sensitive product, moisture pick by this means can be quite rapid. Alternative materials to wool are either plastic shapes or plugs of expanded polystyrene, polyethylene or polyurethane foams. Closures can also be obtained which incorporate spring extensions. Such closures may have chambers which hold desiccants. Transit tests (vibration/drops) would be advised to check whether space fillers are necessary.

Closuring

It is not long since the stoppered or corked bottles were the basic containers for both the pharmaceutical and the toiletry trade. Although these still exist, their use rapidly declined with the advent of the screw-necked container. In more recent years glass has used wadless closures which started as screw versions but can now be applied and removed by other means: plug, twist-off, lever-off, etc. In these forms the flexibility of certain plastics have been utilised to provide both the resistance and the resilience required of a closure. Although press in/over closures can be applied at a higher speed than screw caps, tolerances for bottle neck and closure have to be tighter.

Screw finishes follow recognised standards for shallow, medium deep and deep finishes, etc. All must ensure adequate thread engagement between cap and bottle so that an even pressure is applied over the entire sealing surface—if the closure is wadded or flowed in, this can be checked by the 'wad' impression. If less than of a turn of thread of engagement occurs (possible on a standard shallow finish by a combination of low start of thread on the bottle, over-thick wad, and high thread run-out in the cap) then the cap is likely to tilt and make an unsatisfactory seal. Screw finishes use two basic types of closure—prethreaded (metal or plastic) or rolled on (metal or plastic). Prethreaded closures usually rely on the torque being applied by the spinning action of the cap-holding chuck. Some machines' application torque can be read directly from a gauge, but more usually closures are checked on a separate instrument and recorded as unscrewing torques. As there is a tendency for unscrewing torques to have a timetemperature relationship, checks should follow an agreed schedule.

Although loose closures or low torques obviously run a leakage risk, high torques contain other dangers such as distortion of the closure and customer removal difficulty. Excessive torque can cause cold flow loosening of thermoplastic closures and the doming of metal and plastic caps. If the former is then knocked or flattened (stacking), a low torque can result. Softer metals can also flow or distort (e.g. aluminium alloys) if subjected to excessive forces.

Rolled-on caps can offer some advantages on torque control provided that the bottles, caps and wads are of a good commercial standard. The procedure of applying top pressure to ensure a good seal with the wad and then rolling on a thread to retain the seal offers very effective sealing. However, as the metal employed is an aluminium alloy which is considerably softer than tinplate, the thread must be well formed on both the bottle and the cap, or the threads will over-ride when the closure is replaced and retightened.

The principle of applying top pressure and then affixing it in that position while the wad is compressed is also used on most vial closures, where an overcap is subsequently locked under a bead by either clinching or rolling. Rubber discs or plugs provide the resilient and resistant part of the closure. From a range of natural and synthetic rubbers, properties can be varied in terms of moisture and gas permeation, chemical resistance, etc. and acceptability for irradiation or autoclaving. The industry has yet to discover a replacement for rubber in one essential property for injectable products, i.e. the ability of a needle to pierce without tearing or splitting and reseal upon needle withdrawal. In spite of this advantage, rubbers present problems when they are pierced in terms of shredding or fragmentation (small rubber particles removed by friction between rubber and needle) and coring (pieces of rubber actually cut out by the needle bore—usually associated with the design of the needle point, size, bore and sharpness of the needle heel) (Figure 6.19). Rubber closures for pharmaceutical usage are briefly dealt with under 'Homogeneous liners' later in this chapter.

Whatever the type of closure used on a glass container, the sealing surface is of prime importance. It is critical that this is even and smooth with no sharp features. Mould split lines should be inconspicuous, or alternatively a seamless neck ring can be used so that the risk is completely removed. Sealing surfaces may be radial, flat, stepped, sloped, etc., as indicated in Figure 6.20. The pressure applied by either top pressure or screw torque is taken up by the wad (impression) making intimate contact with the sealing surface. Hence there is either a high pressure confined to a limited area (i.e. raised ring contact) or a lower pressure when it is spread over a greater area, as presented by a broad flat sealing surface. Torques therefore have a

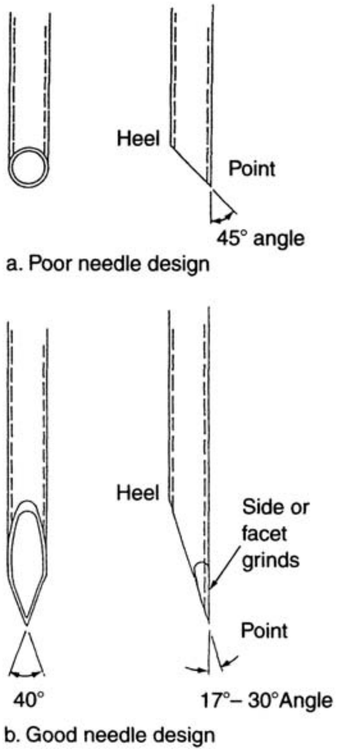


Figure 6.19 Needles for injectables

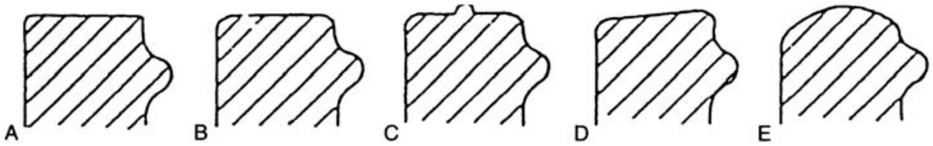


Figure 6.20 Sealing surfaces: (E) is preferred

direct relationship with the surface area, hence as the neck size increases so increased torques are required. Similarly there is a relationship between the neck size and apparent closure efficiency, as moisture pick-up tests with a desiccant show increasing moisture gain with widening diameters (see Table 6.2, p. 253). This may mean that wider diameter finishes are not advisable for some products but since the product quantity may also increase, the gain per unit weight of product may not be significantly different.

Glass in the form of ampoules offers the apparent facility of a near-perfect primary closure in the fusion of glass. This does produce a perfect pack in terms of compatibility (assuming the product is compatible with glass), nil exchange with atmosphere, etc., but difficulty in opening together with the hazards involved lower its overall performance. It is difficult to break open an ampoule either by using a file, or snapping at a score (OPC, one point cut), or at a ceramically fired-in ring, without spicules of glass arising. The presence of such spicules is undesirable, although various opinions have been expressed on the actual risks.

Bottles using wadless bore-type seals may need better quality neck finishes than conventional screw caps because bore seals exert an outward force which may cause cracks or similar imperfections to proliferate. Instances of necks ‘cracking off have been reported.

Special mention should be made of closures for IV solutions. The use of any screw closure with an inner rubber wad or plug always presents an unscrewing risk due to a watch spring effect. In addition, threading may hide a contamination due to residual cooling water. An overseal-type closure, similar to that employed for vials, appears to offer advantages (DIN Standard).

Labelling

Labels may be applied to the main body of the bottle, to the neck, or may enshroud the closure (TE). Each label must be designed for a selected bottle area allowing tolerances for the bottle, the label and the process by which it is applied. A label should be applied to areas of large radius, as several changes of radius within a limited area will cause creasing. Provided that the glass surface is free from silicones or surface lubricants, one of a number of labelling processes may be used, i.e. label plus adhesive, delayed action heat sensitive or pressure sensitive.

An additional critical aspect is product security, i.e. an insurance that the correct label is applied to the right product. Reel-fed labels offer advantages over precut or bundled labels, but even with reel-fed labels there is a tendency for a bar code (or similar coding) to be incorporated onto the label at the printing stage. This is then electronically scanned either just prior to container labelling or immediately after it. The legal requirements for pharmaceutical products are making more and more demands on the product label, i.e. identity including official name, strength, quantity, product licence, manufacturer, batch no., expiry date, etc. This is thereby increasing the difficulties associated with product security. Frequently colour is used to differentiate products and while this has advantages, colour-blind users may find problems, therefore there is no substitute for careful reading and clear and concise text. It is here that we find an obvious difference between many pharmaceutical and OTC products. Ethicals have to maintain a degree of professional confidence to pharmacists, doctors, veterinary surgeons, etc. and must therefore display this by simplicity and clarity. On the other hand, certain proprietary medicines frequently rely on both visual impact and the ability to convince the user of efficacy.

OTC products may cover all extremes in order to create some individuality. Therefore we have simplicity, such as printing of black on white or white reversed out of black, to half tone printing in up to seven colours. The reader may say that the ability to apply a label to a glass container bears no relationship to the design. In some instances this may be true, but on many occasions problems can arise from the design—even the thickness of ink can play a part. Similarly, application of a varnish to protect the ink will reduce water loss through the surface, so that when an aqueous adhesive is applied to the under side, the label will curl more rapidly. One must therefore select an adhesive of the right tack together with the proper smoothing down of the label by wiping pads or rollers. On heat sensitive labels the varnish must not contain solvents which activate or plasticise the adhesive.

As a general rule, labels with radiused corners (not for wrap around) are easier to handle on automatic equipment.

Wrap around labels are suitable for parallel-sided containers. Before committing to a wrap around label it is essential to check that the container does not taper. If it does, it is advisable to have a gap between the two ends of the label. Machinery which rolls on the label from a leading edge may give rise to an unsightly effect, as the label tends to follow a spiral if the container has a taper.

Siliconising or other surface treatments, particularly on the outside of injection vials, can lead to labelling difficulties or the label dropping off on storage. Any glass container which has received a treatment either inside or out should have an adhesive stability check. Silicones tend to creep and internal spraying could affect the outside. Silicone coatings normally do not produce any extraction hazards. Labelling problems may also arise where plastic coated glass is used.

Cartoning and outerisation

Filled glass containers may be cartoned, directly outerised or shrink wrapped. This secondary packaging must be considered in the container design as a means of providing adequate protection against mechanical hazards. Among these effects, vibration is one hazard which results in labelling scuff and damage. Round containers tend to rotate under transit vibration and all shapes tend to show some up and down movements. Any movement can cause scuffing if the label inks are not dry or rub-resistant. The use of cheaper carton board can be a false economy if this leads to surface damage of a label. Certain protective varnishes are also abrasives—that is, once the varnish has started to rub, damage is accentuated by the abrasive nature of the varnish powder created.

Bottles can be designed to minimise label damage by the use of recessed areas. These should be sufficiently deep to allow for variations in the surface uniformity but not so deep as to cause glass distribution problems. Labels applied to bulged bottles or zones of prominence obviously run a risk of concentrated rub. Heavy containers may need to be retained in cartons with base locking flaps (200 g or more in weight).

Labels provide little in the way of light protection unless the base is thicker than normal, selectively coloured (i.e. black), or a foil ply is incorporated. Plastic sleeving (shrink or stretch) as well as coatings applied by the bottle manufacturer have been used on light weight bottles to reduce container weakening due to surface damage.

Warehousing

The stackability of finished stock is a final factory consideration prior to the evaluation of transit hazards—fortunately, glass is a strong material and can take at least part of the stacking pressures. Dangers therefore relate to the effect on the closure rather than the container. Undue pressure can be transmitted to the cap wad, thus inducing a compression set which reduces the seal efficiency. Compression and transit vibration may also increase such an effect to the point of closure failure.

Transit damage

The fragile nature of glass, from impact damage, exposes many risks during transportation with the result that a nil loss can only be insured against by overpacking. One therefore accepts that reasonable handling is expected with occasional exceptions and that there is a recognised economical level of outer packaging. This is frequently achieved by a combination of cartons, internal carton fitments and fibreboard outers with or without internal fitments. The use of shrink wraps with and without base (and top) trays or nests is growing, and brings with it new palletisation requirements. The designer of a pack for a glass bottle must consider the protection requirements. A study of the bottle design and laboratory drop tests (burst tests are also useful) should indicate weaknesses which require selective protection. Where possible, containers should be filled to the normal filling height as the air space or ullage may affect results (water hammer effect).

The degree of protection afforded by individual cartons may be varied by board type and caliper, internal fitments, or even packaging inserts. There are advantages in having single corrugated pieces with the corrugated outwards—the board then acts as a double faced liner and high spot rub between corrugations and labels is avoided. Fine fluted corrugated as used for cartons provides another bonus.

Glass and the environment

Today no chapter on any packaging material is complete without a reference to the problems it may create in terms of disposal, pollution, litter, and the four Rs: recovery, recycle, reuse and reduce (e.g. light weighting).

Glass represents approximately 5–9% of waste by weight but as it is chemically inert, does not burn, rot, putrefy or degrade, there are no direct pollution hazards. Crushed glass is beneficial to land fill and in incinerators glass containers can assist in aerating the mass and thereby improve combustion.

In various surveys glass has emerged in a strong position, particularly in terms of recycling and reclamation. Resalvaged glass is primarily being used in three ways:

1 new containers (via cullet)—a Swiss plant is using 100%
2 as Glasphalt for road surfaces (still under experimental survey)
3 as bricks and blocks and as glass wool insulation in buildings.

However, glass as litter remains a serious problem. General education together with adequate and proper disposal facilities will undoubtedly reduce this hazard, but broken glass must still cause concern. Glass, however, has advantages over most other materials as it can be readily cleaned and reused, or recycled via bottle banks as cullet. In the latter case, other than the risk of admixtures (colours and glass types) no deterioration has been reported in properties.

Special pharmaceutical containers

As one of the earliest usages of bottles and jars was for drug and cosmetic products, it is natural that many of the first specialised containers bore names which became associated with the pharmaceutical industry. Glass containers can be broadly divided into narrow-necked (including sprinkler) and wide-necked—these correspond roughly with the descriptions of bottles and jars. Many general names relate to the cross-sectional shapes, i.e. round, oval, triangular, hexagon, squares, flats and panels.

More specialised container names include the following.

1 Winchesters (UK): This term is widely used in the UK and covers a range of capacities from 0.5 fl.oz upwards, although the Winchester quart containing 80 fl oz. was the best known (see Figure 6.12). These have now transferred to metric sizes, 15 ml to 2.5 l.
2 Carboys: These usually exist in two shapes, balloon shaped of either 5 or 10 gallon capacity or a cylindrical or straight side form of 2, 3, 5 gallons. Metric 22.5 to 45 l.
3 Cylindrical rounds, Boston rounds: Conventional cylindrical bottle with near flat shoulders, 5 ml to 2 l.
4 Jars: Parallel side cylindrical containers bearing no shoulder. Used mainly for creams and ointments. May be white flint, amber or opal glass.

Tubular glass containers

Tubular glassware deserves further mention, as it finds specialised usage in the pharmaceutical industry and in many textbooks on glass, detail is confined to blown glass.

Limited use was made of tubular glass containers prior to 1917, when Charles Danner introduced the first method of continuously drawing glass tube. This discovery led to the greater use of containers made from tubular glass as these then offered certain advantages:

1 lower weight (blown glass was much thicker and therefore heavier)
2 thinner and more even wall control
3 the ability to produce a hermetically sealed pack, an ampoule (early usage)
4 an ampoule met the need for sterile (unit dose) products
5 competitiveness.

These early containers used soda glass tubing. With the further mechanisation of the shaping process in the early 1920s, ampoules which had already been produced by hand became one of the first large usages. Many of these had rounded bases. Neutral glass containers were introduced in the late 1920s and today most ampoules use neutral glass.

Ampoules

Standards exist for a range of ampoule shapes and sizes with variations on the neck and the method of opening. The ampoule can be broken at the neck restriction either by scoring or by having a ceramic point (ring or spot) baked on during the manufacture thus causing a weak point. However, ampoules breaking on a ceramic colour can cause coloured particles to fall into the product. This has led to an alternative where the ampoule is scored and then has a coloured ring above or below the score to indicate the break point. In this way the break does not occur at the coloured ring, thus avoiding ‘coloured’ contamination. OPC (open point cut) ampoules are often now preferred.

Ampoules are normally supplied in plastic boxes with a tray lid and band plus an inner covering to minimise the ingress of particulate contamination. Recently there has been a tendency towards the use of wide stems as this facilitates cleaning and filling at high speed. However, it makes the sealing operation slightly more difficult.

Presealed ampoules can be used without a washing process, i.e. the manufacturing process produces a sterile and relatively clean ampoule. Special equipment is required to handle these so that the vacuum retained in the sealed ampoule does not draw in glass particles when it is opened. Preheating prior to opening can ‘neutralise’ the vacuum by using a flamed opening method. Washing is otherwise an essential stage in the use of ampoules, and specialised machinery with various combinations of ultrasonic vibrations and jets of water, steam or air is available for this purpose from companies such as Bosch, Strunck, Neri and Bonotto.

Ampoules may be sterilised by dry heat or steam autoclaved after filling provided the product will withstand this process. On-line sterilisation often uses dry heat at over 300°C for a controlled period.

Following filling and sealing, ampoules are inspected for seal and visual contamination. The seal or leakage test was performed by immersion in a water/dye solution under vacuum. It is debatable whether the test fully detected minor cracks or capillary holes through which microbiological contamination could occur. High-voltage tests which detect through cracks are now more effective.

Contamination in the form of particulate matter or glass spicules can be viewed by either direct light or polarised light. Although a Coulter counter can provide useful data, it has not been ideal for use in regular QC type counts. The ultimate objective must be to exclude glass particles from the site of the injection.

Ampoules may be preprinted or printed after filling. Preprinted ampoules can use ceramic inks which are printed by the screen process and then fired on. Printing after filling gives greater stock flexibility but requires extra security precautions during the time when the ampoules bear no identification. Printing after filling can be done either from rubber stereos or by silkscreen. The latter can use special inks such as the latest epoxy resin-based inks which can provide an acceptable degree of permanency. Self-adhesive plastic labels are currently finding more use.

The current usage of the ampoule is virtually static. Although it was one of the first unit dose containers, it is anticipated that alternatives such as cartridge tubes and prefilled syringes (glass or plastic) will ultimately take over a major share of the ampoule market.

Typical ampoules are shown in Figure 6.4.

Vials

Vials are parallel side containers with a flat or concave base with a variety of neck finishes. These were popular in the 1920s and 1930s, when they first used cork closures followed by the more conventional screw finishes. The majority of these are produced from soda glass, when used for tablets and capsules.

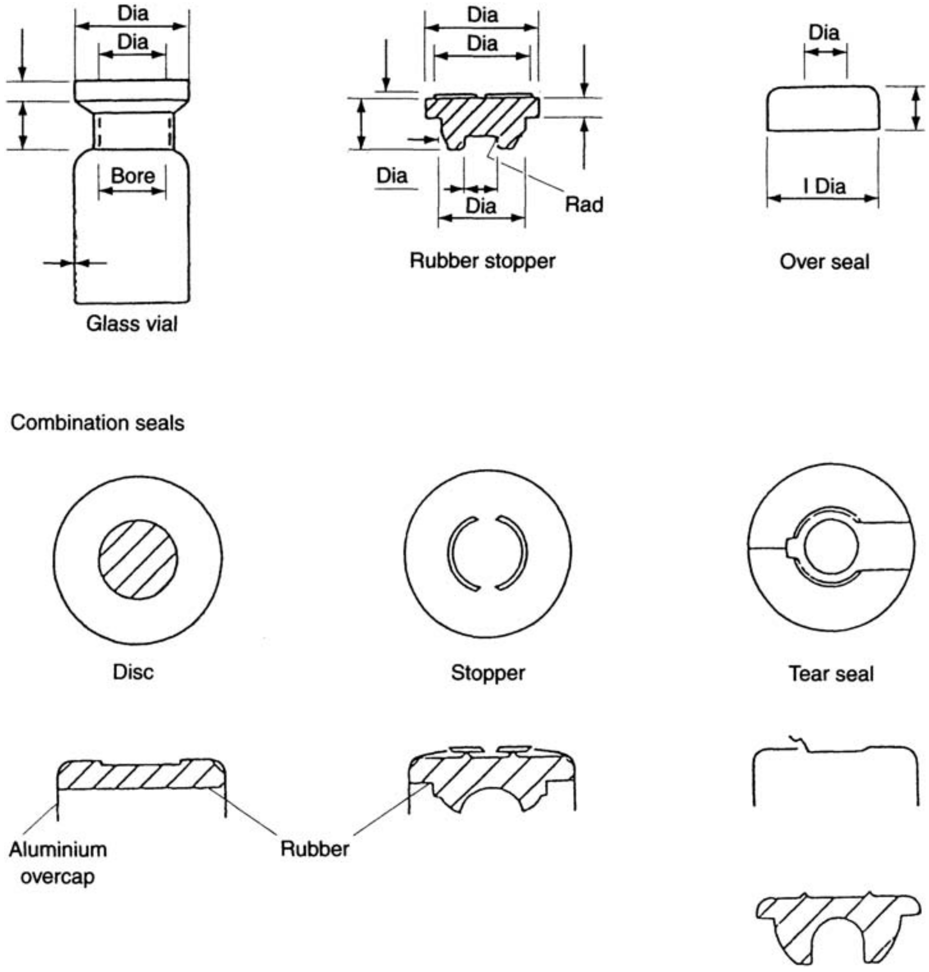


Figure 6.21 Typical combination and conventional seals

The advent of the multidose injection vial with its rubber plug and aluminium overcap increased in use with the discovery of insulin and then penicillin. Insulin made the use of neutral glass essential but when penicillin was presented as a freeze dried powder, soda glass proved reasonably satisfactory, particularly as the life of the solution was dated once the water for injection was added. Injection vials can still be obtained in either neutral or soda glass and occasionally in treated soda glass. Larger vials may be made by conventional blowing techniques as well as from tubular glass. Vial usage has recently been extended by the advent of lyophilised biologicals.

Rubber closures for injectables are outlined under ‘Special closures for pharmaceutical products (sterile products)’ below. Various types of rubber, plug design and over (cap) seal may be employed. A range of standard neck sizes are available (13 to 20 mm). Rubber discs or plugs can be fixed into the overseal—these are usually known as combination seals. Although offering advantages in the closuring operation (only one item to be fed instead of two), washing techniques are more complicated and there is always a contamination risk from metal particles.

Aluminium overcaps may have a perforated metal, plastic flip-off or peelable foil cover. Figure 6.21 shows typical combination and conventional seals. Vials have also been introduced for unit dose packs using either an aluminium two-piece tear-off closure with a Saran coated pulpboard liner or a peel-type seal.

Cartridge tubes, disposable syringes

The use of a glass tube with an end cap seal and movable plunger is another early use of a unit dose injectable. After many years of use in the dental trade in conjunction with a resterilisable metal syringe, further applications were found with other pharmaceutical products. Thus when plastic disposable syringes became available, glass cartridge tubes became the first obvious choice, thus leading to high-volume quantities. The next stage was to combine the cartridge tube and syringe, thus creating a glass dis posable syringe. Syringes are also available with two compartments (bi-compartmental syringes) which allow unstable parts of a pharmaceutical formulation to be kept separate and then mixed immediately prior to use.

With packs relying on a rubber piston to effect the injection, this must both release without sticking and then move smoothly with the minimum of force. This may be assisted by including lubricants in the rubber which subsequently migrate to give a surface film, or by siliconising or coatings.

Closures for cartridge tubes are invariably based on aluminium overseals with or without a tear-off cap which are clinched or rolled on. Syringes may either have a needle mount or have a needle already fitted. Both usually employ rubber or plastic overcaps for protection and are supplied in a sterile outer pack.

Aerosols

The use of glass bottles for aerosols has received mixed comments on the risks involved. Although glass offers greater flexibility in design than cylindrical metal cans, it is essential that the breakage risk is safeguarded against either by good bottle strength/design or adequate bottle strength plus an external coating of a flexible plastic (usually PVC). Uncoated glass bottles are usually used in conjunction with low pressure aerosols (less than 25 lb/in^2 at 21°C). Coated bottles do not usually contain excessively high-pressure formulations.

Glass aerosols inevitably cost more than metal cans but offer plus features on appearance, which is highly desirable for toiletries and cosmetics.

The valves are set in an aluminium overseal (which is frequently polished and anodised or lacquered) and clinched or rolled under an external bead on the glass finish. Finishes range from 13 to 20 mm.

Future potential

What does glass offer for the future? It still serves the pharmaceutical and cosmetic industries well in offering effective, attractive packs. If it were not for the breakage risk, glass would offer the best product protection with distinct advantages relating to hygiene, inertness, zero permeation, sterilisation by heat, etc. Ultimately, a glass pack is as effective as its closure.

The percentage of glass used in pharmaceuticals reduced over the period of 1987–1991, although the overall production of glass remained static. Thus one might predict a slow decline but not a drastic drop, as glass usage is still expanding in certain parts of the world. However, under conditions of material shortage, glass is the least likely to be affected and therefore could enjoy further success.

The marriage of glass and plastic, originally started with the plastic coating of aerosols, has shown a continuing trend for the future. Coated glass, which involves very thin coatings to improve the colour range and strength, shows the greatest promise. Coatings of both organic and inorganic origins are being employed. The latest involves a thin coating of silica. From a pharmaceutical aspect the FDA acceptance of glass rarely presents problems—it therefore encourages the choice of glass as a packaging container. Surface attack and shedding, however, can be a problem, particularly in detection and identification. This can be done with a scanning electron microscope fitted with an energy dispersion analyser. X-ray fluorescence now provides a fast means of analysing glass.

Closures, caps, seals and stoppers

'A bottle can only be judged by the effectiveness of its closure.' The subject of closures, briefly discussed above, is now dealt with more fully. The specific suitability of glass as a recipient of a closuring system may be as one use or multi-use types. The latter should be easy to apply, open and effectively reclose until such time as all the product is used. This ideal may clash with the requirements of a child-resistant closure, but this is adequately covered if the word 'easy' is applied to adults and a phrase such as 'difficult to open by children' is added. With a child-resistant closure it is important that an adult finds it easy to reclose, as failure to do this defeats the very objective that one is trying to achieve. The one-use closure is widely used in the pharmaceutical industry and is in some instances specially designed to prevent reuse.

The primary objective of a closure is to effect a seal, and this is usually achieved by contact between at least two components, one which is relatively hard and resistant to pressure and the other which is soft or pliable and therefore receptive to compression (a ground glass stopper is an exception). A seal can also be made between two pliable or flexible materials, but either or both has to be supported by a rigid background or framework. In order to provide an effective seal on a ridged glass bottle, the closure must provide both resilience and product resistance. There must also be uniformity of compression so that the seal is effective over the full circumference of the container's sealing surface. In this combination glass can offer a fully hermetic seal which permits no exchange between the product and the outside atmosphere.

A seal can be secured by one or more of several basic closuring processes:

1 screw on—by thread or lug (single or multi-start)
2 crimp on or clinch on

3 roll on (in or under)
4 press on, i.e. push in or over
5 heat
6 adhesion
7 vacuum or differential pressure.

Although closures are important to all types of pack, this is particularly so with glass, where any exchange between the product and the external environment can only occur via the closure system. A glass pack therefore relies on its closure effectiveness, but it also must be remembered that function during use and ultimately disposal is also part of the overall ‘fitness for purpose’.

Although a wide variety of closure systems are described in Chapter 11, those particularly important to glass are described in detail below. As closures and closure testing in general remain a weakness for many packs, no apologies are given for some overlap with Chapter 11. The two chapters contain complementary information.

Sealing materials

Prior to the invention of screw closures, corks, glass stoppers, pulpboard discs and parchment covers were the main closures. Historically, prethreaded screw closures have consisted of a threaded shell containing a wad or liner and a facing. The wad or liner may be made from cork agglomerate (gelatin or resin bonded), pulpboard, feltboard, plastic or rubber. It provides a resilient backing which receives the compression. In the case of screw closures the compression is due to the application of a controlled torque. Other closures, e.g. roll on, clinch, press on, may achieve this by the simple application of top pressure. Under the normally recommended torques, composition cork compresses by about 50% and pulpboard by approximately 20%.

The facing or liner material in direct contact with the product must be compatible with it, i.e. must not impart anything to or extract anything from the product. However, in the selection of a liner, factors in addition to compatibility must be considered, for example.

1 appearance
2 caliper—liners if too thick or too thin can reduce closuring efficiency or in certain circumstances prevent a seal being made
3 removal—should give a smooth removal without sticking or tearing; silicone coatings can sometimes be used to improve release
4 permeation—gas and vapour transmission
5 shelf life—must not deteriorate or break down
6 heat resistance—necessary when hot fills or heat sterilisation procedures are employed
7 economical—cost must be acceptable
8 function—a liner must not become distorted or fall out in use, i.e. must maintain a good fit; must continue to accept pressure or compression without bottoming
9 cleanliness, i.e. not create particles or support microbial growth.

There are two main classes of liners, namely heterogeneous and homogeneous. The former consists of a separate facing material laminated to a resilient backing; the latter consists of a single material which serves as both a facing and a backing. The main materials used are as follows.

Heterogeneous liners

1 Laminated papers—these materials are usually laminated to paper and include foils and polymers detailed in Chapter 11.
2 Coated papers

- Thermosetting resins coated onto (and into) paper are now obsolete in the UK but are still used in some parts of the world. They are not covered here.
- Thermoplastic coated papers: These include PVdC, vinyls, polyethylenes and occasionally polypropylene; more recently SiO_x and carbon coatings have been introduced.

Homogeneous liners

Cellulosic materials

Cork, feltboard, pulpboard—used widely as a wadding material, but have limited use in pharmaceuticals and toiletries without a facing.

Polymeric materials

1 Rubber: Still has limited use outside of injectable products; see Chapter 11, specifically relating to natural and synthetic rubbers. Has specialised applications for injectables.
2 Polyolefins. Polyethylene and polypropylene—some use as a separate disc or wad, but are now widely used in the form of wadless closures where the closure acts as its own wad.
3 Fluorocarbons and chlorocarbons: PTFE may be used as a separate disc for strong acids, alkalis, etc.—a very resistant material.
4 Plastic foams: Foamed polyethylene, polystyrene, polypropylene, and vinyls. These are also finding uses as a backing material, being an economical replacement for composition cork and pulpboard. While they exhibit similar advantages to flowedin liners over the cellulosics, additional advantages are obtained in product compatibility and permeation resistance depending on the facing used. EPE is now widely used, with compression factors of 20% and 50%.

Flowed-in compounds

These are essentially a variation on the liners described above, but they are applied *in situ* as the name suggests rather than as a separate disc. They may be applied to the whole area of the cap top or at the edges or within a sunken ring. Materials used as plastisols, organosols, latexes, etc. may be based on aqueous dispersions (rubber and synthetic rubbers) or solvent solutions or dispersions of synthetics in organic solvents. Flowed-in compounds generally provide a good sealing medium but have limitations related to compatibility/migration and moisture permeation. A flowed-in compound offers the following features.

1 Can be operated on a full automatic system at high speed with the minimum of waste when applied to metal closures.
2 It is clean and dust free (cf. cellulosic-based liners).
3 The closure can frequently be rewashed and reused as it is not wetted.

However, there are disadvantages.

1 Difficult to use with certain plastic closures due to the high drying and curing temperature which is about 171°C, but retention is aided by cap design.
2 Solvent-based compounds require a special extraction plant. Residual solvents can cause problems (safety hazards).
3 Aqueous dispersions dry slowly. It is important that all traces of water are removed. There is also a possible odour hazard. These are now preferred.
4 Frequently contain migratory ingredients, or the compound may adsorb from the product. Therefore some compatibility limitations.
5 Investment in plant is high (see (2) above).

Economics of use of flowed-in liners resides in replacing a full conventional liner by a ring or restricted area of flowed-in compound. This especially applies on wide diameter closures. Most widely used are PVC and EVA plastisols.

Finally, the use of flowed in compounds is particularly significant due to supply restrictions on natural cork.

Screw closures

Screw closures based on single (continuous) or multi-start thread constitute the most widely used form of closuring. Prethreaded closures made from metal or plastic rely on achieving an adequate torque which is measured as N m or lb force inch to effect a seal. In general the unscrewing torque is 50–75% of the application torque, but variations occur according to the materials, time elapsed, temperature conditions and, in the case of thermosetting closures, humidity.

Torque control is particularly important with some thermoplastic closures which if given excessive torque will exhibit cold flow. Most countries have standards for single start screw finishes, such as the GCM1 400 series in the USA or BSI R3/2 and

R4 in the UK. Progress is already being made in Europe on a series of standard finishes which will ultimately be common to the EU.

The GCM1 series includes a wide range of finishes, of which the 400 series is the most popular. Some of these are given in Table 6.1.

The tolerances of both the cap and the glass screw finish are critical in a number of areas, including the following.

Diameter—cap and bottle finish

- Clearance (e) between cap thread (E) and bottle neck wall (E)
- Clearance (t) between cap wall (T) and bottle neck thread (T)
- The minimum value of e varies from 0.004 inches (100 μm) for an 8 mm finish to 0.014 inches (350 μm) for 63 mm.
- The minimum value of t varies from 0.002 inches (50 μm) (8 mm) to 0.008 inches (200 μm) (63 mm).

These tolerances should provide adequate allowance for both bottle and closure ovalities.

The maximum clearances are equally important, as too much clearance can lead to the cap tilting or over-riding.

- The maximum value of e varies from 0.016 inches, 400 μm (8 mm) to 0.059 inches, 1.475 mm (63 mm).
- The maximum value of t varies from 0.016 inches, 400 μm (8 mm) to 0.053 inches, 1.325 mm (63 mm).

Table 6.1 Finishes of screw closures

No.	*Type*	*Diameter (mm)*	*Threads per inch*	*Turns of thread*
400	Shallow CT	38–120	8–5	1
405	Shallow CT with depressed thread	18+	8–5	1
425	Shallow CT with depressed thread	8–15		2
415	Tall CT (deep)	13–28	12–6	2
410	Medium tall	18–28	8–6	1.5
430	Tall CT four cut	18–38	8–5	1

Height—cap and bottle

For critical appraisal the external bottle height should be measured against the internal cap height with the wad fitted and an allowance made for the correct degree of wad compression. A cap should not stand proud, as this can lead to an unsightly appearance, or bottom on either the bead or the shoulder of bottle or jar.

Thread start

The thread start on both cap and bottle determines, particularly on a shallow finish, the length of thread engagement and therefore the number of turns or part turns required to tighten or release (Figure 6.22). Insufficient thread engagement can lead to cap tilt or uneven wad compression. This may also be caused by an over-thick wad.

Thread starts on plastic caps are virtually fixed by the tooling. In metal caps where the thread is rolled or formed, thread engagement can suffer due to a high thread start, a poorly defined run-out or when the thread is improperly formed (i.e. of insufficient height or depth, etc.).

However, if a bottle thread starts too high (nearer to the sealing surface) this may cause problems with plastic caps which employ a stopped rather than a run-out thread or where caps use a wad retention recess—see Figure 6.23. General metal and plastic cap drawing are shown in Figures 6.24 and 6.25. A typical glass finish is shown in Figure 6.26.

Pitch

Caps and bottles must have the same thread pitch or tpi (threads per inch). The number of threads per inch reduces as the neck diameter increases i.e.

- 8 mm finish=15
- 63 mm finish=5.

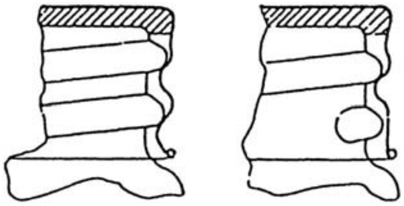


Figure 6.22 Illustration of the desirability of prolonging the thread as near to the brim as possible: 0.05 inch start (left) versus 0.1 inch start (right)

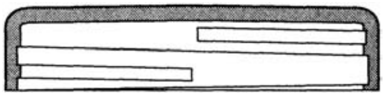


Figure 6.23 Type of plastic cap that is liable to prevent a seal: the upper end of the thread is stopped too low, and is liable to meet the top end of the thread before it is screwed home

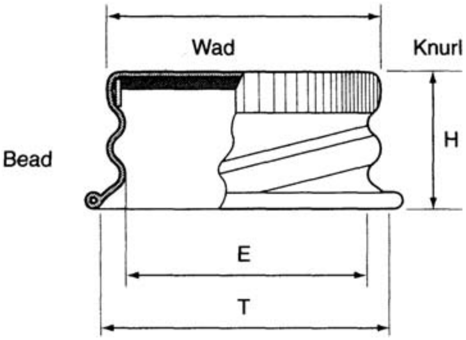


Figure 6.24 Metal screw cap

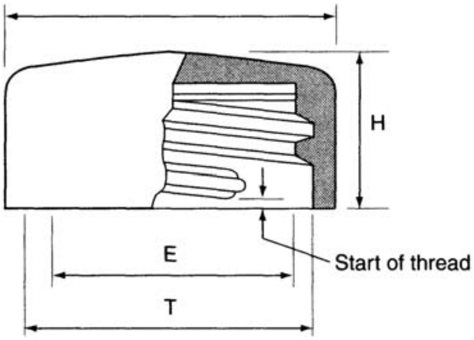


Figure 6.25 Plastic screw cap

Most glass screw finishes use a thread form based on 60° (earlier semi-round threads were employed). Metal screw caps also follow a common shape, but with plastic caps various configurations have been and still are used (see Figure 6.25).

Closuring diameter—relationship with seal efficiency

The effectiveness of a seal bears a direct relationship to the container diameter because:

1 the wider the container diameter, the more difficult it is to achieve a uniform sealing surface which lies in the same plane, i.e. perfectly flat
2 the wider the diameter, the greater is the seal area.

Therefore a wider diameter container must have a more resilient wad. Even with a good wad, higher moisture figures should be expected on wider diameter containers (see test data in Table 6.2). However, as larger containers hold greater amounts of product, the critical factor is the moisture gain per item or per gram of material.

For the tests documented in Table 6.2, containers contained dried calcium chloride with wadless PP caps applied to a normal torque. Although the results include some

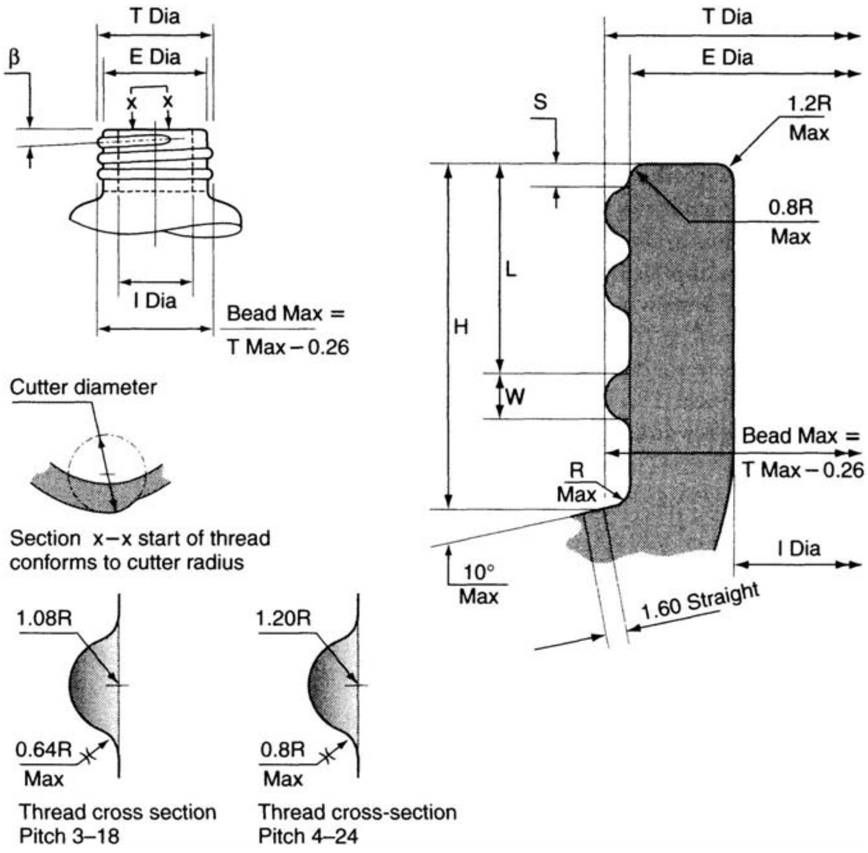


Figure 6.26 Typical drawing of bottle finish

Table 6.2 Results of moisture tests

		25°C 90% moisture gain (mg)			*37°C 90% RH moisture gain (mg)*		
Container	*Finish*	*1 month*	*2 months*	*6 months*	*1 month*	*2 months*	*6 months*
Glass 30 ml	22 mm	2	6	6	2	7	10
Glass 60 ml	24 mm	3	11	33	9	47	61
Glass 100 ml	28 mm	32	122	198	11	434	531

moisture gain due to permeation through polypropylene, a flowed-in compound lined cap gave comparable figures.

Multi-start as distinct from single start threads have two or more threads. These provide a more even pressure on the liner and require fewer turns to tighten or remove, e.g. on a four start thread, engagement is obtained in a turn. A conventional single start closure requires a minimum of turns of thread engagement to ensure that even pressure is obtained, and with less than turn of engagement a distinct tilt and/or a poor wad impression results.

Rolled-on closures are covered in Chapter 11.

Other means of closuring

Clinching, crimping, swaging, spinning or rolling

Each of these primarily applies to metal closures, although a similar action could be carried out with certain thermoplastics under the influence of heat. Basically each operation starts with the application of top pressure (like the RO seal) followed by a shaping action which locks metal under a retaining feature.

Clinch-on applies a simultaneous bending action over the total circumference of a skirt. Crimped-on applies both flutes and a bending action in the case of closures—the prime example is a crown cork closure invented by W.Painter of Baltimore in 1882. The word ‘crimped’ is frequently misused when ‘clinched’ is correct. Rolled-on and spun-on use wheels to bend in a skirt extension, thus providing a similar effect to clinching. Both clinched and spun-on metal closures are used in injection vials, IV solutions, cartridge tubes and glass aerosols.

Press-on

Press-on, push-on, push-in have gradually expanded in their applications, particularly on tablet vials and bottles. All are made of plastic.

Heat or adhesive seal

Finally, containers can be diaphragm sealed using heat (including induction sealing) or adhesive either as the sole closuring means (i.e. peelable tops for unit dose preparations) or in conjunction with any of the other closures previously mentioned. Diaphragms can be a useful means of forming a tamper-evident seal, e.g. used in conjunction with a child-resistant closure.

Dispensing closures

A closure may serve additional purposes to its prime objective of product retention. Dispensing closures offer pouring aids, facilities for providing drops, sprays, or a measured (metered) dose. Perhaps one of the earliest dispensing uses was the dropperpipette which locked into a retaining hole in a conventional screw cap. This is still used today, with the bulb made from either natural or synthetic rubber or silicone elastomer, and a pipette of either glass or thermoplastic material.

Bore/plug fitments can be used to improve pouring or to restrict the flow so that a drop can be dispensed. Various pump systems can be fitted to glass bottles in order that a metered volume can be delivered as a ‘shot’ or as a coarse or fine spray. These employ special break-up features according to the product characteristics and the spray requirements. These devices have found wide usage for nasal products and have further potential in the pharmaceutical field. Captive closures can also incorporate a tear ring, thus creating a tamper-evident closure. These are invariably a wadless type of closure which can make its seal on any of three areas on the glass finish:

1 internal, cone or valve type seal—seals on either the lead-in edge or the sides of the bore
2 land or top seal—seal is made on the container sealing surface
3 external seal—seals on the edge or sides of the outer container wall.

Any combination of the above can be employed (see Figure 6.27).

While pharmaceuticals have many closures in common with other groups of products, certain closuring systems are unique to pharmaceuticals. These are dealt with below.

Special closures for pharmaceutical products (sterile products)

Fusion of glass—ampoules

Although ampoules have already been mentioned as an example of a near-perfect closure, all closuring systems require some means of checking their effectiveness. The basis for testing the seal of ampoules was immersion in a solution containing a dye and applying a vacuum (vacuum dye test). This is now being superseded by electrical conductivity testing, or capacitance testing (Eisei, Densok, etc.).

Intravenous solutions, multidose vials

The majority of sterile products rely on the use of a rubber closure (synthetic or natural) which is held in position by some form of overcap. The latter may be a metal screw cap or seal which is clinched or rolled under a bead. The rubber may be a disc or a plug and be applied either as a combination seal (the disc or plug is pre-fitted in a metal seal) or as separate components.

A closure for an injectable product has to fulfil the following requirements, which are additional to or more critical than the requirements for other closures.

1 It must make an air-tight seal and maintain sterility (i.e. not admit any microorganisms).
2 It must be compatible with the product—not extracting or absorbing from the product or imparting anything to it.

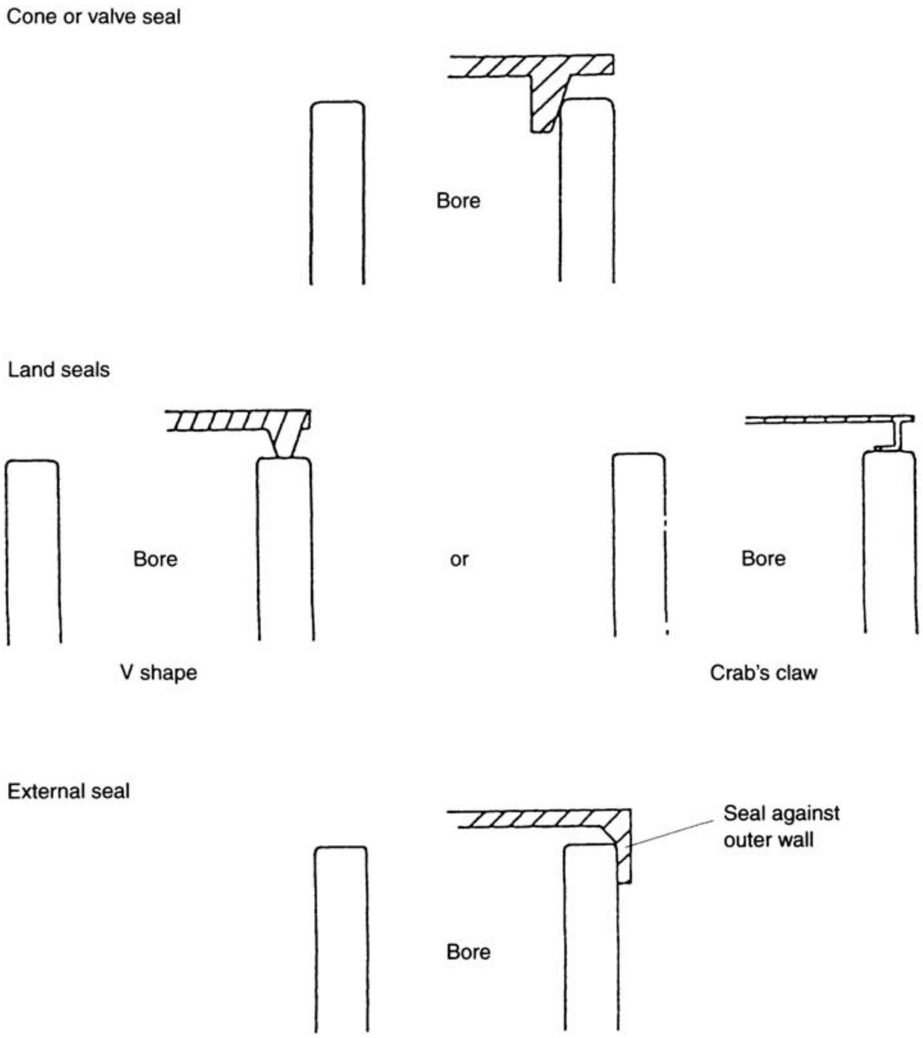


Figure 6.27 Types of seal

3 It must be clean or capable of being cleaned to minimise possible particulate contamination.
4 It must be pierceable by a wide range of needle sizes and needle types, without leaking, splitting or shedding fragments by either friction (i.e. fragmentation) or coring.
5 It must reseal when needle is removed.
6 It must be capable of sterilisation at least once or twice by autoclaving. Gaseous or gamma sterilisation may be other possibilities.

Rubber meets most of these requirements, but so far no plastic material has been found as a substitute. The nearest alternative is a silicone rubber which is expensive, has a relatively high water vapour permeability and readily absorbs preservatives.

The range of rubber materials includes natural and synthetic-based materials. Special designs of rubber (e.g. castellated) are available for lyophilised/freeze dried products. Surfaces may be coated, e.g. with PTFE or Parylene, to reduce any extractability risks.

Summary

Closures are important to all packs, but particularly so with glass, where any exchange between the product and the external environment can only occur via the closure system. The total effectiveness of a glass pack is therefore reliant on its closure. However, function during use and ultimately disposal are also part of the overall fitness for purpose.

Appendix 6.1:
Gauges

Gauges form an essential tool in the checking of glass containers. The main types are as follows (Figure 6.18).

1 Ring gauge—usually separate minimum and maximum gauges.
2 Parnaby gauge.
3 Single and double fork gauges:

- single fork—separate maximum and minimum
- single fork—with both maximum and minimum
- double fork—shaped like a letter H, covers maximum and minimum gauges.

4 Window gauge—usually for square or rectangular containers.
5 Channel gauge.
6 Box gauge.
7 Sleeve gauge.
8 Bore gauge:

- single
- minimum and maximum on separate ends
- minimum and maximum on same end.

9 Height gauge.
10 Verticality gauge.

It is important that gauges be correctly positioned during use—this usually means holding the gauge in a plane at 90° to the dimension being measured. If the gauge is tilted it can give an incorrect result.

Appendix 6.2:
Glass terminology, test procedures and gauges

The fact that glass is a long-established packaging material has led to the gradual development of testing procedures and terminology.

Glass terminology

Figure 6.28 gives the basic terminology which is expanded in the text. A bottle consists of a finish or neck ring, a neck, shoulder, body and bottom or base. The finish varies according to the closure requirements. The bead, which is also known as the transfer ring (it supports the bottle when it is transferred from the parison to the finishing mould), may either be prominent, i.e. remain visible below the closure, or be concealed, i.e. covered when the closure is applied. The sealing surface may either be seamless (obtained by using a 'thimble' in the mould) or seamed. In the latter mould part lines are visible on the sealing surface.

The neck and shoulder may exist as two definable shapes or in certain circumstances may converge whereby they are virtually one (i.e. ill-defined).

The concave base is frequently known as the punt, and may be well defined as in certain wine bottles.

Glass defect terminology

As with many established industries, terminology can vary from company to company. Efforts have therefore been made to standardise certain terms. The list in Table 6.3 serves only to introduce the subject—a fuller list may be obtained from glass manufacturers or manufacturing federations.

Terms not involving fractures or cracks

1 Ring

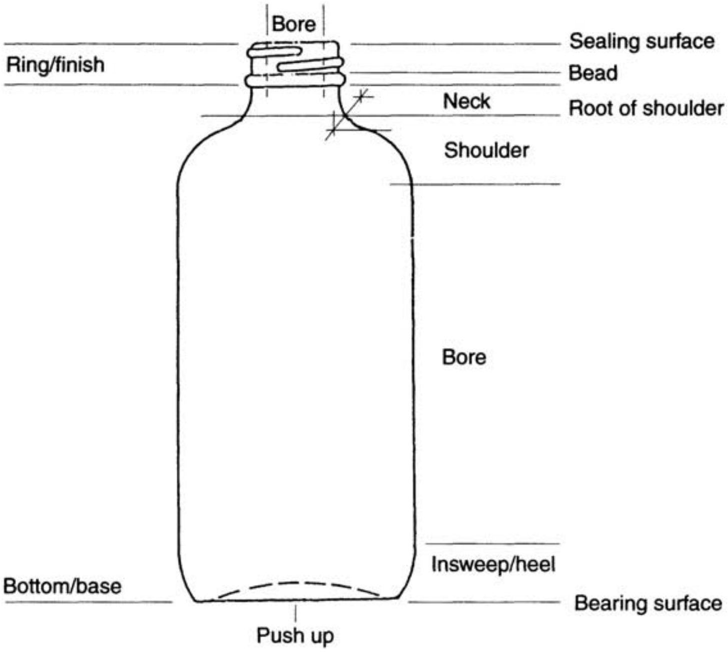


Figure 6.28 General terminology (glass bottle)

- Bulged ring: profile bulged out of shape though not necessarily out of specification.
- Bent ring: a ring which is tilted to one side.
- Dipped ring: a severe dip or depression in the sealing surface.

2 Neck and shoulder

- Bent neck: a neck which is tilted.

3 Body defects

- Sunk: where the body is sunk inwards.
- Bulged: where the body has bulged outwards.
- Uneven distribution: varying thickness of bottle wall.
- Corrugated: undulating surface.

Table 6.3 Terms involving fracture or cracks

Defect	*Description*	*Example*
Split*	A fracture normally exceeding 6 mm in length which penetrates into the glass surface.	Split ring—a vertical split extending from sealing surface. Split body—in any direction in the body.
Check	A fracture normally less than 6 mm in length which penetrates into the glass surface.	Checked ring—anywhere on ring. Checked body—anywhere on body.
Crizzle	A surface 'fracture' of any length which does not penetrate into the glass to any appreciable extent. It reflects light in a similar way to checks and splits.	Crizzled sealing surface. Crizzled ring—elsewhere on ring than sealing surface.
Tear	A fissure as opposed to a fracture. Can be of any length or width. Allows a piece of paper to be inserted into it, i.e. can be felt as opposed to splits, checks and crizzles, which can rarely be felt — usually does not reflect light in the way a fracture does.	Tear under ring—usually occurs horizontally and directly under ring. Body and bottom tears—any orientation in body or bottom.
Chips	Distinct loss of a fragment of glass, which has not caused it to break.	Chipped sealing surface, chipped ring, body, bottom, etc.
Broken	Where a piece of glass has broken away from the main body or is so fractured that it will break away.	

* Splits can often lead to bottle failure and are therefore more important than checks or crizzles.

4 Bottom

- Wedged bottom: glass is thicker at one side than the other; unsightly but not thin enough for rejection.

5 Thin corner: wedged bottom with a thin corner which warrants rejection.
6 Rocky bottom: rocks from one side to the other.
7 Spinner: will spin freely due to central bulge.

The third group above covers general defects, for example the following.

- Bird swing: see Figure 6.17—a thread of glass extends between two internal points in either neck or body.
- Stuck: lump of glass annealed to outside of container.
- Stones: refactory or batch inclusions in the glass.
- Seed: small bubbles in glass.
- Blisters: large bubbles in body of glass.
- Skin blisters: a soft surface blister which can be broken
- Hair or air line: a faint single line in glass surface.
- Wrinkle or washboard: a wrinkle or series of horizontal marks, one above another like a washboard.
- Spike: a projection, usually sharp, on inside of container.
- Glass inside: a piece of glass annealed to inside of container.
- Bloom: a hazy deposit or film, soluble in water, as found with type II glass.
- Weathered: a white surface deposit, not soluble in water.

Other defects refer to specific areas, e.g. thin shoulder, thin body, thin bottom. In each of these the area is too thin for safety. These are only some of the many possible defects and faults (see Figure 6.17).

Specifications or dimensional defects can generally be detailed as over maximum or under minimum. Some categories may be further divided: under minimum bore, tight bore (slightly below minimum); choked bore, well below minimum. Typical AQLs for critical, major and minor defects are detailed in Appendix 6.3.

The following are examples of performance tests applied to glass containers.

Thermal shock test

The samples are placed in an upright position in a tray which is immersed into hot water for a given time, then transferred to a cold water bath. Temperatures of both baths are closely controlled. Samples are examined before and after the tests for outside surface cracks or breakage. The amount of thermal shock a bottle will withstand depends on its size, design and glass distribution. Small bottles will probably withstand a temperature differential of 60–80°C, and 1 pint bottles 30–40°C. A typical test uses a 45°C temperature difference, hot to cold.

Internal bursting pressure test

The most common instrument is the American Glass Research increment pressure tester. The test bottle is filled with water and then placed inside the test chamber. A sealing head is applied and the internal pressure automatically raised by a series of increments.

Each increment is held for a set time. The bottle can either be checked to a preselected pressure level or the test continued until the container finally bursts.

Annealing test

The sample is examined by polarised light in either a polariscope or a strain viewer. The strain pattern is compared against standard strain discs or limit samples. Normal annealed glassware shows limited strain patterns usually with colours of red/blue—greater intensities of strain are indicated by colours ranging from white/orange through red/purple to green, yellow and white. Both extremes indicate strain due to either tension or compression. The interpretation of strain is frequently one of experience. When a glass bottle leaves a mould the outside tends to cool more rapidly than the inside, leaving the inner surface under a state of tension. This strain is normalised in the lehr, where the whole container is raised to dull red heat and then cooled slowly.

Vertical load test

The bottle is placed between a fixed platform and a hydraulic ramp platform which is gradually raised so that a vertical load is applied. The load is registered on a pressure gauge.

Leakage tests

These may be based on product tests, vacuum tests, feeler gauge tests, or newer special tests as given in Chapter 11.

Autoclaving

The ability of a filled or empty container to withstand autoclaving may be checked. It should be noted that when large numbers of glass containers are autoclaved some occasional breakages can be expected. Those that break are assumed to be substandard containers with certain defects such as surface damage which are difficult to detect by prior inspection. Autoclaving may be used to test the possibility of extractives from the glass surface. As a general rule 60 min at 121°C is considered equivalent to a shelf life of half to one year.

Limit tests for alkalinity or chemical resistance

These are employed to check the alkalinity extractives. The pharmacopoeial tests may be based upon surface extraction tests (i.e. type II surface treated glass) or crushed glass where the glass composition is checked (type I neutral glass).

Appendix 6.3:
Packaging material specification

Notes

1. Where company has approved buying samples for goods, any orders for goods of the same description subsequently placed by the company shall, unless otherwise indicated, be deemed to be placed on the basis of such buying samples as well as on the description and/or specification, and in all such cases the goods shall conform both to such buying samples and the description and/or specification.
2. The supplier shall effect no physical or chemical change to the product or its method of manufacture without the prior agreements in writing of the company.
3. The company reserves the right to revise or amend the specification after formal notification to the supplier.
4. Sampling, inspection and classification of defectives is conducted strictly in accordance to .... (the AQLs for this are shown overleaf).
5. Visual defect classifications

CRITICAL

Defects which are likely to result in hazardous conditions for potential users or packing operatives.

MAJOR

a) Defects which are likely to materially reduce the usability of the container or end product.
b) Defects which are likely to result in the product not meeting the required standard.

MINOR

Defects which are not likely to materially affect the usability but are a departure from normal commercial standards.

AUTHORISATION:
SUPPLIER: DATE:
RECEIVING COMPANY: DATE:

References

1. Moody, B., *Packaging in Glass,* Hutchinson Benham, London.
2. Pfaender, H.G., *Schott Guide to Glass,* Chapman & Hall, London.