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CLOSURES AND CLOSURE SYSTEMS

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Introduction

With the majority of pharmaceutical products, the closure is an integral part of the pack, hence the word 'pack' covers both the container and the closure system. The latter may involve a unit dose or multidose where an included feature (e.g. heat seal, weld, peelable seal) or a separate feature (e.g. screw cap, lever lid) defines how the system functions. Because in most circumstances the pack is only as effective as the closure employed, a successful marriage between container and closure is essential to the product shelf life and its acceptance during use. In some instances a closure may serve a relatively simple function, i.e. act as a dust cover; at the other extreme it has to be hermetic, i.e. it permits no exchange between the product and the external atmosphere. This differs from a sterile closure system which retains sterility, i.e. prevents contamination from micro-organisms but may permit exchange by permeation of gases, moisture, etc. Sixty years ago there were relatively few closure systems, whereas today there are literally thousands. Closures and closure systems have as a result become both more sophisticated and more complex. This is particularly true when the closure assists in the administration of the product and/or where it incorporates special features to improve safety and security (tamper-evidence, tamper-resistance, child-resistance, etc.). This broadening role for closures and closure systems must cover the full life of the product (storage, transportation, display and use).

A primary function for even the simplest of closure systems is to retain or contain the contents. Safety and security may be necessary to prevent hazards resulting from leakage, seepage, spillage, prevention of pilferage, exposure to the wrong persons (e.g. children) or loss of quality, purity, etc., by some source of contamination, impurity, etc. Closures may also form part of the overall design of the pack and enhance the decorative appeal (image/presentation), act in a functional role during use (e.g. reclosables) or actually assist in the administration of the product (e.g. aerosol valve). Closures also act in a protective/preventive role by restricting ingress (odours, taints, moisture, oxygen, carbon dioxide, mould, bacteria, etc.) and egress (loss by evaporation, loss of moisture, perfume, flavourings, volatiles, etc.).

To the above design and functional factors, must be added those associated with cost and production line efficiency, i.e.

1. application at a required speed
2. equipment availability at an acceptable cost
3. minimum downtime and wastage/losses
4. specific pack/closure or preferably a range of packs (of differing designs and materials, involving packs and closures)
5. meeting the required performance standards
6. acceptable cost, including cost of closure components
7. maintaining any additionally required functions associated with dispensing, tamper-resistance resistance, tamper-evidence, child-resistance, etc.

A closure is therefore an essential part of any basic pack and as such must assist in providing a product with protection, presentation, identification/information and convenience on an economical basis until such time as the product is totally removed from the pack. The latter may be a once-off operation (i.e. it is a one-use or unit dose system) or multiple use in that the product is used over a period, thereby creating the need for a reclosable pack. In all instances the time between the creation of the packed product and its ultimate removal/use while it is still in a satisfactory state represents the shelf life of the product.

In the case of reconstituted products the closure may have to serve two somewhat different roles, i.e. prior to reconstitution where a powdered or crystalline product is involved and after the constitution when the product is in a liquid form. Convenience in use has increased in importance with the growing elderly population who may have impairment of movement, poor co-ordination, poor sight, etc. There is therefore inevitably some conflict between the need for ease of opening/reclosure and childresistance, tamper-resistance, etc. and the fact that many closure systems are becoming more sophisticated by their administration functions.

The closure itself must be clean and sufficiently inert so that it does not affect the product by absorption/adsorption (from the product), interaction or permitting migratory substances to pass from the closure into the product. A closure may also be called on to provide protection against any hazard which may face the product during its shelf life, e.g. climatic, chemical, biological and mechanical hazards. Although the above references to closures may appear to cover only the primary or immediate pack, they are also important to the secondary pack. For instance, a fully taped (H seal) and glued case is more robust than a partially taped case—the better closuring system making for a more rigid unit, which will more effectively withstand both transit and stacking.

Since the closure is an integral part of the total (primary) pack, it cannot be considered in isolation. Thus when the environmental issues are fully considered, more attention will be required on the closure component (e.g. the public is encouraged to remove metal caps from glass bottles before the latter are deposited in bottle banks). Using closures made in the same materials as the containers has been suggested as being environmentally friendly. These, however, can create technical problems.

The initial conclusion is that any pack is only as good as the 'closure' system employed. Not only are closures becoming more complex and sophisticated, but the total functions which they serve are more diverse than many people realise and frequently they do not receive the attention to detail that they deserve. This broad chapter on closures therefore highlights the diversity of the systems employed, and the importance to the pack design, presentation and treatment.

The basis of closure systems

Closures may be achieved by a number of basic means or a combination of two or more, as follows.

Pressure

1 Mechanical pressure, e.g. top, side, internal pressure on a container finish ideally involving a seal between a fairly rigid material and one which is more resilient. Includes screw closures, plug seals, lever lids, etc., which create an interference fit between two materials.
2 Atmospheric pressure (pressure and vacuum): although a similar mechanical seal occurs to (1), this is initially achieved by a pressure differential (e.g. vacuum sealed tin).

Temperature

1 Welding/heat sealing—involves the direct and indirect application of heat, usually under pressure, for a given time (dwell) followed by a cooling period, so that a bond is made between two materials.
2 Electrical, e.g. ultrasonic, high-frequency/radio frequency, impulse, induction sealing. Basically a modification of the heat seal process.

Adhesion

Achieved by aqueous, solvent, hot melt, etc., adhesives or self-adhesives, cold seal materials. Solder is a metallic adhesive system. Solvent bonding is a chemical adhesive system.

Closure evaluation and performance against egress and ingress for reclosables

Closures usually have two stages of evaluation. These involve:

1 initial developmental evaluation by which pack and closure are selected and approved (note that this involves factors in addition to egress and ingress)
2 ongoing evaluation whereby incoming closures, production produced finished packs, display, use (and any subsequent customer complaints) are monitored and assessed, i.e. the basis of normal QA and QC.

In order to define the 'seal or closure effectiveness' for any closure system, some clarification of terminology is essential. One basic means of assessing a closure is by loss or gain as measured by weight or volume, as follows.

Loss from product (egress)

Although loss can occur to solid-based, gaseous or liquid-based products, only liquidbased are dealt with here.

- Leakage: liquid (or contents) positively found on external surface of the pack or closure.
- Seepage: example is where there is no obvious sign of leakage but liquid (or dried contents) may be found on container finish (threads) or on inner surface of cap.
- Evaporation: loss is normally detectable only by weight change. Occurs between seal area and possibly the main body of the container.
- Permeation: difficult to distinguish from evaporation but weight loss occurs by permeation through the sealing media, the closure and possibly the body of the container, if these are permeable.

Note that since evaporation/permeation involves the loss of the 'solvent', this may also be detected, by analysis or other leak detection techniques ('sniffing').

Gain to product, i.e. ingress

Usually associated with moisture pick-up, but can be related to any movement inwards by solid, gaseous or liquid substances. Moisture gain is detectable by weight increase or product analysis.

Microbiological ingress

Critical to sterile products, i.e. ingress of bacteria, mould or yeasts, and requires special detection techniques.

Gaseous exchange

Ingress or egress of gases such as oxygen, carbon dioxide, nitrogen may be associated with product deterioration or organoleptic changes. As with the above, loss or gain may occur via leakage/seepage or permeation mechanisms. Gas permeability increases as the temperature rises where plastic materials are involved.

Terminology related to closure efficiency remains fairly loose in terms of both ingress and egress. The USP XXIII offers tests for tight and well-closed containers based on the rate of moisture ingress into closed containers containing a desiccant under selected conditions of temperature and RH. Correlation between such movement inwards and outwards and that associated with flexible materials also requires further quantification, especially when measured by modern leakage detection instrumentation. The latter involves detection of pressure changes based on positive and negative pressure systems and the detection of various gases by a range of 'sniffing' systems. The means of generally defining closure efficiency requires further quantification.

It should also be noted that closure evaluation can rarely be assessed by one simple test, as the seal or fit between components may change with time and the surrounding climatic conditions. Typical evaluation stages could involve:

1 immediately closure has been applied
2 after a period of storage, possibly followed by transportation (involving compression and vibration)
3 at point of use
4 during and after periods of use.

Closure assessment and control: some general factors

Closures and closure systems may depend on or be influenced by a number of factors:

1 documentation/information/specifications
2 people (processing and usage)
3 machinery/instruments
4 the materials, container and closure
5 the environment—storage and application
6 warehousing and transportation
7 the product.

For instance, the apparently simple operation of applying a screw cap to a screw finish on a container can be broken down to well over 100 possible influencing factors. Examples of these are as follows.

Torque

An application torque may be given as between *x* and *y* lb ft ins or N m. The removal torque will change according to how long after application a check is made, the environment in which it has been stored, the type of materials used, etc. Hence removal torques may differ considerably after 10 min, 2 h, 24 h, 7 days, etc.—therefore the time factor between application and removal may have to be assessed and documented. Such changes are usually greater when plastic caps are applied to plastic containers.

However, a closure and container which provide a satisfactory marriage may still not be fully satisfactory, if either the container partially collapses or compresses during application of the cap or top pressure during stacking, or vibration plus top pressure during transportation causes unacceptable loosening of the closure. This is related to thorough testing during the development stages.

Information

Incorrect use and interpretation of information, the keeping of inadequate or inaccurate records, poor investigational techniques, improper adjustment or validation/ checking of recording instruments and machines, are a few examples how people may influence a closure system.

Wear

Machinery wear, changes due to vibrational effects, excessive speed, etc, may give rise to machine-dependent problems. Although it may be frequently assumed that a fitter knows his or her machine, it does not necessarily mean that he or she understands every process, as this ultimate detail may only be established by high-speed photography. Such an investigation may show distortion of components, excessive or short throw, vibration, etc. Another common feature is that fitters (or even engineers) with excellent machine training may lack adequate training on material aspects, closure specification, etc. Regular monitoring of instruments associated with the machine or those used for measuring is important. Operator training is essential to any effective, operation, plus regular validation of all instruments.

Materials

The materials employed for the container and the closure have a significant influence on the design, the process by which they are made and the performance. The materials may include the following.

- Metals—tinplate, tin free steel, aluminium, aluminium alloy, etc., and even stainless steel (vessels for bulk storage must also have effective closure systems).
- Glass—neutral, treated and soda glass. Although it is mainly used for containers, glass stoppers can still be found.
- Plastics—based on both thermosetting and thermoplastic polymers. Note that these have higher coefficients of thermal expansion than metal.

Since most closures put large dependence on their surface properties, these may be modified by the use of coatings, lacquers, etc. With plastics the constituents may be either at the surface (slip additives, lubricants, etc.) or migrate to the surface with the passage of time. These surface agents may also be changed or modified by processing, flame treatment, etc. The trend towards improving the barrier properties of plastics by coatings, e.g. fluoride treatment, silica oxide coating, may also influence closure performance. The process by which a closure is manufactured may introduce design restrictions (e.g. shape and depth of thread in the case of metal). In the blow moulding of plastics, injection moulding invariably gives better control over the neck dimensions and quality compared with an extrusion blow moulding process. Quality of design is therefore a major factor to consider in closure performance.

Environment

The environment may be critical to both the closure and the product as both may suffer from expansion and contraction due to temperature or RH changes. Other factors should not be excluded as a source of problems. For instance, static problems can increase with thermoplastic caps if the RH is low. This is particularly likely to occur during cold weather. The answer may be humidification of the atmosphere, avoiding addition of an anti-static agent to the plastic, avoiding a hot fill or neutralising charges by earthing or electrical means (ionised air). Artificially created environmental conditions may also cause problems, e.g. applying a ‘cold’ closure to a hot filled product.

Warehousing and transportation

Certain closure systems may be changed by top pressure from stacking and/or the effects of vibration or the combination of vibration and compression during transportation. For example, cartoned cylindrical containers are likely to rotate during transportation, thereby possibly reducing the closure torque. Top pressure may also weaken the seal impression on a variety of closure systems.

User or usage tests

The overall performance of a closure must include the ‘use’ period. Thus although a closure may enable a product to reach its point of use satisfactorily, it still has to serve certain functions such as tamper-evidence/tamper-resistance, child-resistance, reclosure, etc., in use.

Interaction between closure and pack (e.g. the black slurry which may occur with aluminium collapsible tubes), and possible adhesion between closure and pack (e.g. as may occur with sugar- or syrup-based products), are typical of what could occur if usage tests were omitted. Simulated use tests are particularly important with aerosols, pump systems, etc., which combine the closure with a dispensing system.

The product

The product factors which may need consideration include viscocity, cleanliness of fill, whether product froths or is corrosive, coefficient of expansion, volume to vacuity or ullage ratio, etc. Note that alcoholic based products have a higher coefficient of expansion than water, hence need a higher level of vacuity. Vacuity levels normally lie between 2% and 10%. Certain more volatile materials and chemical based products will create internal pressure according to the vapour pressure exerted for a given temperature. In certain instances, e.g. with peroxides, hypochlorites and similar products, pressure may be controlled by the use of venting closure systems.

Initial approach to closure assessment and control

The above examples should establish that any closure or closure system requires an indepth knowledge of a number of areas, which are usually identified from experience rather than being found in textbooks.

An example of this lack of basic information can be found in the standard 40 cm oval nasal spray bottle which usually consists of an LDPE bottle, LDPE plug, dip tube, and a thermoset or thermoplastic cap. The cap may incorporate one of four types of primary seal, a spigot (which fits into the plug orifice), a half ball (which fits into a recess or socket in the plug), a raised ring, or a flat sealing surface.

The cap is also usually shaped to make a secondary seal on the plug shoulder, this being a means of centralising the cap and preventing excessive top pressure on the plug tip (thus avoiding distortion of the plug tip and closure of the orifice by cold flow). In practice even some of the existing packs tend to leak or seep, particularly if subjected to excessive changes in temperature or when transported in ‘pressurised’ holds in aircraft. Although this may be due to a combination of incorrect tolerances on the components and/or the use of insufficiently controlled capping torques, finite causes are difficult to establish without large-scale statistically controlled programmes (on a scale usually not acceptable to industry in terms of time and human resources). Factorial experimental design at the suppliers should reduce this risk. ‘Quality’ of the container neck will also vary according to whether it is moulded by an injection blow or an extrusion blow moulding process.

Evaluation therefore requires a logical and basic approach which in the case of ‘reclosables’ could follow the following stages, using egress as an example.

1 Evaluation of drawings, i.e. for containers, closures, closure fitments (plugs etc.) involving all relevant tolerances. Study of these drawings may establish that a closure can or may be either ineffective or suspect. What cannot be done by the study of drawings is an evaluation of the level of efficiency. This can only be done by the tests described later.
2 Checking samples with drawings. If they do not match, decide whether the drawings should be altered to actual dimensions or the samples readjusted to the drawing dimensions. (Note that decisions partly depend on whether tooling is new or established.)

3 Product egress. Depending on the material from which the pack is made, egress may occur via the closure and the pack. If this does arise, then it will be necessary to measure:

(a) total loss from pack
(b) loss from closure
(c) loss from container component.
Although (a) should equal (b)+(c), possible constituent absorption/adsorption cannot be ignored.

Rate of loss will be related to temperature, the vapour pressure of the product in the pack and the vapour pressure of the product constituents in the surrounding atmosphere. In the case of a water-based product, the product will have both a vapour pressure and a relative humidity above the liquid, each of which will change according to the temperature. Actual loss will be related to the 'gradient' between the product 'headspace' and the external atmosphere, i.e. the greater the difference between the two, the greater will be the 'loss' (in theory).

However, temperature increase will generally change the internal RH/vapour pressure differently and independently to the external atmosphere, hence the rate of loss will vary as conditions change. Constant storage at one condition (e.g. 25°C 75% RH, 30°C 30% RH, 37°C 90% RH) will therefore not be easy to equate with 'actual' conditions. Product vapour pressure and RH above the solvent will also depend on whether 'salts' are dissolved therein, since the presence of a solute in a solvent lowers the vapour pressure. Note the vapour pressure of a substance (liquid or solid) is the pressure exerted by its vapour when in equilibrium with the substance.

Relative humidity is defined as the vapour content as a percentage of the concentration necessary to give vapour saturation at a given temperature. It also can be expressed as the ratio of the vapour pressure of the water vapour contained therein to the saturated vapour pressure of water vapour at the same temperature. A rise in temperature therefore reduces the RH (provided there is no addition of water vapour) and a drop in temperature raises the RH until such time as 100% RH or dew point is reached. Excess water then condenses out—i.e. there can be an internal 'shower effect' within the product or pack. RH can be measured by a wet and dry hygrometer or other instruments.

Atmospheric pressure

One atmosphere is defined as a pressure exerted at a sea level temperature of 15°C (1013.25 mbar) or the pressure exerted by a mercury column (of defined density and under defined gravity) of 760 mm height. Examples of some typical vapour pressures over a range of temperatures are given in Table 11.1.

Actual 'loss' will only be optimised if the solvent emerging is immediately removed (i.e. is swept away by air or a moving atmosphere). Build-up of the solvent in the external atmosphere will therefore slowly retard rate of loss, as the external concentration rises.

From this it should be seen that if an aqueous product is stored in a permeable pack, moisture loss will relate to the external environment and whether it is 'static' or is subject to motion or movement. Storage at, say, 37°C 90% RH will be relatively restrictive to moisture loss, whereas 37°C 30% RH will have a significantly greater 'gradient' and losses could be relatively high (particularly if held in a venting cabinet with a fan).

Egress or loss may relate to any substance (liquid, solid or gas) which exerts a vapour pressure under normal storage conditions, which usually lie between (−20°C) deep freeze conditions and somewhere around +55 to 60°C. However, moisture loss (and gain) is critical to many products, hence requires special consideration. As mentioned previously, whether loss is solely via the closure and/or pack depends on the materials employed for each. In order to separate the loss from each it may be necessary to carry out controlled experiments where either the container or the closure is covered or coated with an impermeable material (wax dipped or foil covered and sealed) so that permeation from one can be quantified.

This is particularly relevant where plastic packs and plastic closures are employed. In the latter case it may additionally be necessary to seal off the closure as loss may occur both through or around the seal, and through the cap itself (particularly if a wadless system is employed). In such instances 'weight loss' is the normal way of assessment. This is usually more accurate than assessment by chemical or physical analysis unless the loss of moisture causes a readily measurable physical or chemical change.

One final point related to loss is that loss may occur as total product (leakage or seepage), or by permeation coupled to evaporation. Each of these loss sources needs some form of quantification (see above). It should be noted that if product degradation and solvent evaporation occur similarly, chemical analysis may falsely indicate that no change has occurred, i.e. proportional compensation will mislead the conclusion.

Table 11.1 Typical vapour pressures (mm mercury) at various temperatures

	Temperature (°C)							
Material	*−30*	*−20*	*0*	*5*	*20*	*80*	*100*	*120*
Water	–	0.8	4.6	–	17.5	–	760	–
Acetone	11.2	–	–	89	185	–	2790	–
Benzene	–	–	–	–	77	760	–	–
Ethylene glycol (antifreeze)	–	–	–	–	–	–	–	39

Loss by evaporation—use of Lyssy dynamic water vapour tester or similar instruments (e.g. Mocan-Permatran W)

There are a range of instruments which can electrolytically detect the rate at which moisture is given off into a dry stream of nitrogen which either is passed over packs containing a water base or passes through a permeable membrane (having a humid atmosphere on the opposite side). This procedure has an advantage over actual weight loss tests, which need time for equilibrium to be established (particularly if the pack is paper labelled or contains a paper-based wad). Normally the Lyssy dynamic water vapour tester will provide rate of loss figures for a given temperature within 24 h of the experiment start.

Vacuum tests

Whether a pack will leak can also be checked by some form of vacuum test. The vacuum may be drawn on the pack containing the product, or a product of lower surface tension to encourage loss, or held in a dry vacuum chamber or by placing an empty pack under water (the water normally contains a dye and a wetting agent) and again applying a vacuum. In both types of test, product (or air) out or liquid in may detect a defective closure system. The level of vacuum drawn, the time it is held, and the way it is built up and released vary from company to company.

Vacuums employed normally range from 15 to 25 inches of mercury (380–633 mm) and are held for 30 s to 10 min. Rate of vacuum release may also vary (fast, slow). In each of these tests the packs are sealed as per normal production.

Pressure tests

This test can only be applied to flexible packs, as the pack is put under positive pressure by some form of weight/force. A full pack is employed and loss detected by actual leakage. Also, a filled container can be stored on its side for 24 h at 38° C (after filling at a lower controlled temperature) (see CAN/CSA—276. 1-M 90 (Canada) using a three-quarters full container). A positive air pressure test (using a full pack in a reinforced chamber capable of being pressurised) can also be employed.

Combined pressure and vacuum tests

In actual practice a pack may suffer from positive and negative pressures due to changes in environmental air pressures. This may occur due to either transportation via air in pressurised and unpressurised aircraft or changes in air pressure by ground height.

If a product starts at sea level, each rise of 1000 ft will involve a negative pressure differential of (−)0.475 lb/in^2, i.e. 0 to 10,000 ft=−4.75 lb/in^2. It should be noted that pressurised aircraft are pressurised to 8,000 ft, i.e. a negative pressure of (−)3.8 lb/in^2. Since unpressurised aircraft can fly up to, say, 24,000 feet (16,000 ft may be more normal), negative pressure of (−)11. 4 lb/in^2 (16,000 ft=−7.6 lb/in^2 may be found (the figures given are pressure changes).

Typical heights and pressure differential conditions are:

- London—sea level, 0 lb/in^2
- Johannesburg—6,500 ft, −3.1 lb/in^2
- Mexico City—7500 ft, −3.6 lb/in^2

Note that normal atmospheric pressure is approx. 14.7 lb/in^2, and the above are again quoted as pressure changes.

Products being moved by air or between sea level and higher areas can be exposed to both negative and positive pressure differentials. These may cause pack distortion with flexible materials and generally increase the risk of product leakage or seepage. Marginally suspect closure systems may therefore have problems under the situations indicated above. Pressure differentials may be further influenced by temperature changes, particularly those which arise from the conditions associated with moist heat sterilisation, i.e. 108–135°C in the presence of 'steam'. In the case of flexible materials, an overpressure or balanced pressure autoclave is essential to prevent pack distortion and possible leakage during the cooling cycle. Under the higher temperatures of sterilisation some closures may also distort, vent, etc., hence if a good reseal is made after partial cooling, some degree of negative pressure may be created. Actual tests are therefore advised to establish the overall effectiveness of such closure systems.

However, positive and negative pressure tests must be advised if transport by air is to be regularly used (or in areas of the world where altitude differences may cause changes in pressure differentials). In these tests, temperature variations should also be borne in mind.

Transportation and warehousing

Having discussed how egress can be measured under 'normal' static conditions, 'closure efficiency' may still be influenced by conditions associated with transportation and warehousing (see above). Actual or simulated warehousing and transportation tests may be advised as part of a pack-closure evaluation.

The above more conventional procedures (newer procedures will be considered later) might be used to test product-pack efficiency in terms of its protective role against egress during the shelf life of a product. A similar series of tests can be considered where ingress may be the evaluation factor.

Ingress may refer to the following.

1 Moisture.
2 Gases of organic or inorganic origin.
3 General contamination which may be referred to as soilage, spoilage, etc. Contamination may be of a solid (particulates), liquid or gaseous form which may cause physical, chemical or organoleptic changes and can be a carrier of foreign substances (flavours, aromas, bioburden, etc.).
4 Microbiological contamination, included as part of 'spoilage', is totally undesirable when products are sterile. Pathogenic organisms should ideally be absent in products where the presence of such organisms would cause concern (e.g. *Listeria, Salmonella, Clostridium botulinum*).

The function of a closure to maintain a product in a pure and/or uncontaminated state, etc., has therefore an importance greater than product egress. Checking whether such ingress is controlled, limited or totally excluded by the 'closure' may follow the same or similar tests as those used to check product egress. However, some tests may be different, i.e. weight gain must replace weight loss checks. These tests therefore follow a similar order to those used previously, as follows.

Evaluation of drawings

The same comments apply, i.e. while imperfections in the closure/container system may be identified, the effectiveness of the 'seal' cannot be quantified from drawings. Excessive interference fits may actually cause container/closure distortion or, in severe cases, either breaking or cracking of either component. It is important that samples are compared with the drawing to ensure compliance. Any difference needs action on the drawing or samples (see previous notes on evaluation of drawings and checking samples with drawings).

Ingress to product

In common with egress, ingress can occur as:

1 total gain by pack
2 gain via (or through) the closure
3 gain via (through) the container.

Although (1) may equal (2)+(3), certain packs may absorb external constituents and others may migrate from the 'pack' to the product, e.g. certain plastics absorb moisture (e.g. Nylons), hence weight will vary according to the surrounding environment. Plastics which show absorption of moisture may have to be predried before they can be moulded.

Moisture gain can therefore occur as the reverse to leakage and seepage, permeation through the closure or the container, and moisture absorption from the atmosphere in which the pack is located. Since some packs have a series of closures, other than that used by the consumer, moisture gain (or loss) can occur via the secondary closures or seals, e.g. the folded and crimped seal in the case of a collapsible tube, the side and end seams in three-piece tinplate cans, the swaged-in valve cup with an aerosol.

Ingress, however, is not restricted to moisture and may, as indicated earlier, involve any solid, liquid or gaseous form of ‘contamination’. Each of these may enter a pack via an ineffective seal and involve the ‘breathing’ of a pack. This may arise from changing pressures caused by atmospheric pressure variations (natural, changes in altitude), or changing levels of temperature (and RH), which cause the pack and pack contents to expand and contract.

Vacuum tests

Applying vacuum to an effectively sealed pack will mean that the internal atmosphere is under positive pressure. Under such conditions a flexible pack will possibly expand or inflate; a rigid pack may show no change. Applying a vacuum to a pack showing positive leakage will cause a similar vacuum inside the pack. Releasing the vacuum will allow the external atmosphere (or any external liquid) to enter the pack.

Pressure tests

Placing packs under a positive pressure external to the pack can provide a useful indication of possible ingress. The positive pressure atmosphere may use air, water under pressure, or a concentration of any gas (or liquid) which can be pressurised (see below for further details). For tests involving combined pressure and vacuum, comments apply as for egress.

Transportation and warehousing

Comments apply as for egress above.

Other tests and considerations

Since ingress may have more serious repercussions than egress, additional tests to those above are used to detect both moisture and possible microbiological contamination.

1 Desiccant tests. Dried desiccant tests (as defined in USP XXIII for tight and well-closed packs), provide a useful indication of moisture ingress. Possible desiccants are dried calcium chloride and dried silica gel, but although these usually provide a useful comparison between packs, relating this information to the product may prove difficult, particularly if moisture sensitivity equates with some form of chemical degradation.

2 Microbiological ingress. Bacteria, moulds and yeasts may ‘grow back’ through or via various closure systems. Normal leakage or closure efficiency tests may not establish whether organisms will penetrate through minute or small imperfections in the closure-pack systems. One check to ascertain whether microbiological contaminants will grow back is to contaminate the outside of the closure (or seal(s)) with a contaminated product, or growth media such as a broth, spiked with known organisms. For such tests a temperature of around 37°C (for incubation purposes) is likely to be preferable. Such tests are particularly relevant with sterile products and packs such as aerosols and pump systems, where product contamination would be unacceptable (e.g. wound care, eye care products). However, reproducibility of these as ‘grow back’ remains dubious.

3 Detection of foreign vapour ingress, e.g. leading to changes in organoleptic properties. Changes in flavour and aroma may occur because of foreign vapour entry via the closure. Since some undesirable contaminants (e.g. perfumes) may consist of a multiplicity of chemical substances, each ingredient may be absorbed into the material differently. The resulting off-flavours/aromas in the product may therefore be different to the original contaminant, as some separation of the constituents may have occurred as permeation or diffusion proceeded. Placing a pack in an enclosed concentrated atmosphere of possible contaminants is a useful way of establishing whether ‘foreign vapour’ transfer is likely.

4 Other gas permeation effects. It should be noted that all plastics are to some degree permeable to gases. This means that even when the closure is highly effective, permeation into the pack can give rise to physical or chemical changes. Examples of these are as follows.

- LDPE bottle filled with an aqueous unbuffered product at pH 7.0—after a period of storage a pH shift due to the inward permeation of carbon dioxide is most likely to occur (new pH approx. 4.5).

- LDPE bottle etc. as above, but product is buffered to pH 7.0. In such a case, carbon dioxide permeation will still occur but will not be detected by a pH change. If carbon dioxide reacts with the product (e.g. presence of carbonates could cause precipitation), this hidden ingress may not be considered as a possible cause of change or deterioration.

The above examples should tend to indicate that permeation ingress may occur by either the pack or the closure and give effects which are independent of general closure efficiency

Discussion of egress and ingress should have highlighted the numerous ways in which a closure (or a seal) may need to be assessed or evaluated before a 'closure' can be pronounced as meeting 'fitness for purpose' (for egress/ingress only).

Before other functions, e.g. tamper-evidence/resistance, child-resistance, accuracy of delivery, can be discussed, general technical factors associated with ingress and egress need further consideration. Since these are common to 'seal' efficiency (i.e. ingress and egress) and may define seal quality, they were not covered under the headings used earlier. In the example used below a continuous screw threaded container—closure system has been employed as an indication of the typical variables involved. These are listed in Table 11.2 and then briefly discussed.

Table 11.2 applies to conventional continuous threaded preformed screw closures as applied to glass, plastic or metal containers, but is also relevant to multistart and lug type finishes. Certain features on the container have to be 'matched' against the closure.

Historically, screw closures have consisted of a threaded shell (originally metal) containing a wad or liner with a facing. The wad, which was made from cork agglomerate (gelatin or resin bonded), pulpboard, or feltboard, is gradually being replaced by alternative wadless systems. This provides for a resilient backing into which the seal is 'bedded'. The wad may be backed with Kraft paper and/or hot waxed if required. Although plain wadding may occasionally be used, most have a facing, which must be resistant to the product. Most facing systems are laminated to a sulphite or sulphate bleached paper. It may be one of many materials, as listed in Table 11.3.

In newer materials, such as polythene, plasticised PVC and EPE, it is possible to combine the wad/facing as one material, utilising the combined properties of resilience and resistance. Taking this one stage further, wadless caps can now be made from various plastics: LDPE, PP, HDPE, etc. In addition there are rubber compounds as discs, bungs or stoppers, i.e.:

1 natural rubber (ages, permeable, sensitive to excessive heat, but good on resealing, coring)
2 synthetics (butyl, chlorbutyl, bromobutyl, etc.)
3 silicone—inert, permeable and expensive (see Chapter 12, 'Sterile products and the role of rubber components').

Table 11.2 Typical variables for a container-closure system

Container	*Factors common to both*	*Closure*
	• Threads per cm or inch (pitch) • Thread type, i.e. interrupted or continuous • Thread form—semi-round, 60° (BS 1918), acme, buttressed (BS 5789 plastics), etc. • Thread length (turns), i.e. start to run-out • Thread height (above wall) • Thread base	
Thread OD (overall diameter)	Thread start—style of start (abrupt, tapered)	Thread ID (internal diameter)
Wall OD	Thread helix angle	Wall ID
Sealing surface, width, shape and diameter		Sealing feature (wadded or unwadded)
Finish height		Internal cap height
Material:		• Metal
• Metal—type/style		• Plastic thermoset or thermoplastic
• Glass		
• Plastic		• Preformed
		• Rolled on (metal)
Internal bore ID		Wadless—OD of bore
Parallel bore ID		Intrusion
Wall thickness		Thickness of wall, and head section

Container	*Factors common to both*	*Closure*
Presence of bead or transfer ring		• Style of wad retention, (glued-in, friction fit, flowed-in compound, etc.)
	With tolerances of all dimensions	• External shape, gripping areas (beading, knurling, ribbing, etc.)

Table 11.4 gives an elastomers selection chart.

Prethreaded screw caps

These can be fabricated from the following.

1 Metal—low carbon steel, tin coated, and aluminium, i.e. tinplate—corrosion protection can be improved by use of external enamels and internal lacquers.
2 Aluminium alloys—can also be enamelled, printed and lacquered.
3 Plastics (natural, coloured, metallised, etc.). May be either thermosetting or thermoplastic.

Table 11.3 Materials for facing systems

Material	*Comments*
Aluminium foil (soft)	0.025 mm or the same with a macrocrystalline wax coating.
Tin foil	Very soft but expensive. Gives a good seal.
Polythene	Coated Kraft—usually 0.002 inches (50 m)
Expanded polyethylene foam (EPE)	There are two grades of expanded polyethylene which in compression are similar to pulpboard (compression 10–20%) and compo cork (compression 45–55%)
Saran/PVdC film	Originally a 0.0075 inch DOW PVdC film, but this is inferior to dispersion coated PVdC in terms of moisture barrier.
PVdC coatings	An aqueous coated PVdC, varying in coating weight (an excellent barrier to moisture, gases and reasonably solvent resistant) .
Polyester film (PET) i.e.	50 or 100 gauge, rather hard (0.0005 or 0.001 inches).
Mylar and Melinex	
Solid polythene	Occasionally used.
Solid PVC	Depends on plasticisers.
PTFE facing	0.002 inches very inert, hard and expensive, used with strong acids.
Flowed-in compounds	PVC plastisols, occasionally rubber latex, EVA variants.

Thermosetting, i.e. phenol formaldehyde (PF), Bakelite and urea formaldehyde (UF)

These may be wood, paper or flour filled, but be alert to possible release of ammonia, phenol, or formaldehyde residues from the moulding process. PF can be made by reacting phenol with hexamine (made from formaldehyde+ammonia).

In general (but not invariably) the unscrewing torque is 50–75% of the application torque. Examples of the torque instruments available are Torquemaster, Torquemeter and Kork a Torque. Unscrewing torques may, however, change according to storage conditions and length of time stored. Thermosetting caps, for instance, change dimensionally (moisture and coefficient of expansion) and metal/thermoplastic change mainly due to coefficient of expansion under changing conditions of storage. Phenol formaldehyde caps are slightly more dimensionally stable than urea formaldehyde caps. PF is available only in the darker colours, whereas UF is available in all colours. PF caps will withstand steam sterilisation, but urea will not.

Thermoplastic-based closures

See Table 11.5. The application of a prethreaded cap relies on a torque usually measured as N m, to make a good impression between two surfaces. Ideally one material should be hard, e.g. glass, so that it bites into a resilient (soft) material such as composition cork. The sealing surface of a glass finish may be radial or flat, or in certain circumstances stepped or tapered. Thermoplastic closures are generally less dimensionally stable than metal closures.

Table 11.4 Elastomer selection chart

Elastomer	*Natural rubber*	*Butyl rubber*	*Chlorinated Butyl Rubber**	*Nitrile rubber*	*Silicone rubber*	*Hypalon*	*Chloroprene*	*Viton*	*EPDM*	*EVA*
Resistance against ageing	4	1	1	2	1	2	2	1	2	2
Sterilisable in saturated steam	3	1	1	2	2	1	2	1	2	2
Coring	1	4	4	4	5	4	3	5	2	3
Resistance against mineral oil	5	5	5	1	4	4	2	1	4	4
Resistance against vegetable oil	4	1	1	1	2	3	2	1	3	4
Resistance against aromatic solvents	4	3	3	2	4	3	3	1	4	4
Resistance against permeation of gas	4	1	1	3	5	1	2	1	3	3
Resistance against permeation of water vapour	4	1	1	3	5	2	3	1	4	4
Compression set	1	4	4	2	3	4	2	3	2	3
Flexibility	1	4	4	2	3	4	3	4	2	3
Resistance against heat up to	120°†	145°	155°	130°†	220°	160°	140°†	210°†	125°	120°

1=excellent, 2=good, 3=average, 4=poor, 5=not recommended. * Or bromobutyl.
† Only short time exposure (depends on cure system).
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Table 11.5 Thermoplastic-based closures

Material	*Comments*
Polystyrene (PS)	Hard, rigid, rather brittle: can be embrittled by chemical attack (isopropyl myristate), or crazed.
Polystyrene—medium or high impact modified grades (HIPS)	Reduced brittle factor.
Polythene LD (and LLDPE)	Rather soft, flexible—can be wadless, may stress crack.
Polythene: MD, HD	Less flexible and less soft; HOPE is now very popular.
Polypropylene (PP)	Fairly hard—can be wadless if special sealing 'ring' is incorporated. May be homopolymer (can crack at low temperatures) or copolymer.

Wadless closure systems

Wadless closure systems may be made from thermosetting or thermoplastic materials. The former were earlier used on plastic tubes, i.e. combining the hardness of the thermoset and the flexibility of the plastic tube.

Today wadless thermoplastic closures are used on glass, metal and plastic containers. The seal area may be achieved on the top, internal or external sides of the sealing surface of the container. The internal method of achieving a seal, known as a bore seal, is usually made with a tapered skirt or extending feature in the cap. When the top surface makes a seal this may be matched with a special flexible feature in the cap such as a crab's claw, a raised bead or a flat surface. The container sealing surface may also have raised areas such as ribs or beading. Finally, the outer wall of the container finish may be used as a seal area which matches with a taper or angle in the closure. Although some closure systems have claimed to make a triple seal by making contact within all three areas, the author believes that a single seal tends to be more effective, and bore seals are becoming increasingly popular.

Wadless systems are made from a range of thermoplastics, with polypropylene and high density polythene being widely used.

Plastic caps on plastic bottles

Loss of torque against time has been well documented with plastic caps on plastic bottles. This does not necessarily mean that the closure becomes ineffective, but there are occasions when a low torque only needs the vibration effects of transportation to become an unsatisfactory (loose/leaking) closure. Certain tamper-evident/resistant features such as sealed diaphragms and ratchet-type closure systems are likely to overcome such problems. Having the right combination of plastics may also eliminate or reduce this loss of torque. However, there is the converse where the use of the incorrect combination of plastics, or plastics with undesirable constituents such as lubricants, mould release agents, internal release agents, may actually exacerbate the loss of closure torque. This loss may be associated with thread forms, area of thread contacts, cold flow or creep of plastics involved, lubricants, etc.

Rolled-on pilfer-proof (ROPP) closures

Note that 'pilfer-proof' is early terminology, now replaced by TE (tamper-evident) or TR (tamper-resistant). This process usually applies only to metal shells made from aluminium alloy. But plastic caps with compound lining can also be formed on a container finish. The caps may contain either conventional wadding or a flowed-in gasket. In theory this type of closure provides a more consistent first seal than a prethreaded screw cap in that:

1 the operation of application applies a controlled top pressure which makes a seal between wad and container sealing surface
2 while still held by the top pressure, the thread is rolled into the metal, thus giving a finish which is tailor-made to the individual container
3 in the case of a pilfer-proof closure the skirt is rolled under the bottle retaining bead.

The ROPP closure has two torque measurements related to breaking the seal and the TE feature. Disadvantages can occur with the RO system where the glass finish is not up to standard, causing perforation of wad and difficulties in unscrewing. Reclosure is satisfactory provided the thread is fully formed, but shallow formed threads can be made to override due to the softer alloy metal.

The above in total represents over 100 variables which may exist within a conventional container/screw closure system. If one adds to this the variables associated with different grades of plastic and the constituents which may be contained therein, the torque range applied, the method of application, the temperature/RH of the environment at the time of application, etc., then the total variables can exceed 150 factors. Some examples of how these variables may interact are given below.

Torque

Screw closures 'lock' in position by the interlocking forces applied by the thread of the cap onto the threads of the container. The force applied is varied according to the diameter of the container, with the recommended force increasing as the diameter widens. This locking force is achieved through the contact area of the cap to container, hence the smaller the contact area, the greater the force per unit area of contact, and the greater the contact area, the lower the force per unit area of contact. Since the locking force applied by the thread contact is transferred to the area of seal, how 'effective' this force is in achieving a seal depends on a number of factors, i.e. whether seal involves:

- two 'hard' surfaces/materials
- two resilient surfaces/materials
- one resilient and one hard material.

Resilient materials will undergo a degree of impression or compression according to the nature of the material, the force involved and the area of contact taking the force. The way the resilient material compresses will also depend on how it acts as a resilient or non-resilient 'cushion', i.e. at one end of the scale it may compress and have 100% recovery when the force is

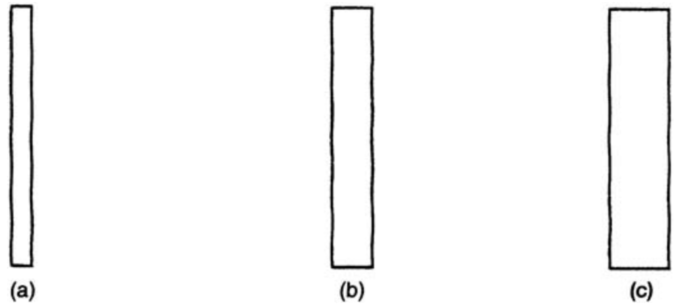

Figure 11.1 Examples of sealing surf aces/walls: (a) 0.75 mm; (b) 1.5 mm; (c) 3 mm (wall OD 25 mm)

removed and at the other end collapse totally with no recovery. This in turn may be influenced by the applied force versus the contact area involved. Three examples are shown in Figure 11.1.

Figure 11.1 represents three sealing surfaces/walls on three different 28 mm necks of an HDPE bottle:

(a) sealing surface is narrow with a width of 0.75 mm and an area of seal of 57 mm^2 (internal bore 23.5 mm)
(b) sealing surface is 1.5 mm across, hence the internal bore is 22 mm and the area of seal is 110 mm^2
(c) sealing surface is 3 mm across, hence the internal bore is 19 mm and the area of seal 207 mm^2.

If a uniform torque is applied to each of the above, then the force to surface area ratio will reduce from (a) to (c). A situation therefore could occur where two of the three gave an ineffective seal, assuming the wadding system was, for example, a faced pulpboard on a liquid-based product, as follows.

(a) The high force per area could cut through the facing and allow the liquid to penetrate the pulpboard, and slowly evaporate, giving rise to leakage and possible microbial growth on the wadding.
(c) With a low force per area and minor imperfections in the sealing surface, there may be insufficient force (impression) to ensure a seal between the container surface and the faced wadding material.

In the above example an effective seal with (b) is assumed.

The transmission of the force applied between the container and closure threads has further implications which depend on both the wall section of the container and the wall sections of the cap (i.e. side walls and top section). In any of these instances the force applied may cause distortion or deflection of the container wall, the cap walls or the top section of the cap. Each in turn may reduce closure efficiency, which in instances may cause total loss of torque, hence a 'no seal' situation may be reached. Examples of this situation are sketched in Figure 11.2. Cap (a) is made from plastic with a very thin wall section, whereas (b) is a much thicker sectioned cap where distortion would be extremely unlikely.

When the situation in Figure 11.2(a) is applied to a fairly thin walled container, both the side walls may splay out (as shown in Figure 11.3) and the top wall section, which may initially dome, may ultimately crack open like a trap door.

The movement outwards of the side walls will depend on:

(a) the wall thickness
(b) the material employed (and constituents therein)
(c) the thread contours on pack and container
(d) the forces on each component and the cold flow-creep properties of each.

Table 11.6 gives some suggested torques for screw closures.

Thread engagement—turn to release

Thread engagement is normally checked by applying the cap onto the container at the recommended torque and then removing it with a slight lifting action until the cap loses thread contact. The degrees or parts of turn engagement are measured from position of tightness to where thread contact is lost (Figure 11.4).

A 180° or turn is usually unsatisfactory as pressure on one side tends to tilt the closure, hence compression is not even over the total surface. A 270° () to 540° () turn is normally considered satisfactory. Although there may be reasons for turns (to centralise a deep cap), this can be considered wasteful in application energy. This engagement will vary accordingly to:

Figure 11.2 (a) Plastic cap with very thin wall section; (b) thicker sectioned cap

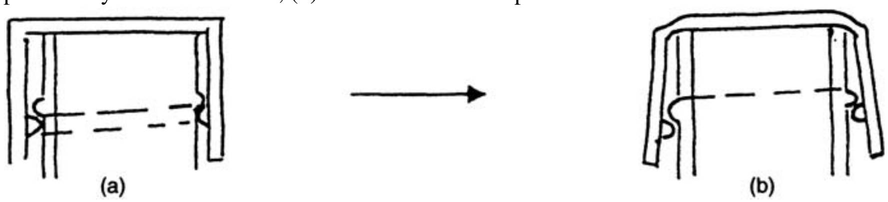

Figure 11.3 (a) Cap at recommended torque; (b) doming in cap head section—side wall distortion could reduce retention torque

Table 11.6 Suggested torques for conventional wadded screw closures (metal and plastic)

Closure diameter (mm)	*Suggested application torque*	
	(range in lb force inch)	*range in N m*
15	6–9	0.69–1.035
20	8–12	0.92–1.38
24	9–15	1.035–1.725
28	10–18	1.15–2.07
33	12–21	1.38–2.415
38	15–25	1.725–2.875
43	17–27	1.958–3.105
48	19–30	2.185–3.405
53	21–36	2.415–4.14
58	23–40	2.645–4.60
63	25–43	2.875–4.945
70	28–50	3.22–5.75

1 N m=8.85 lb force inch=10 kgf/cm. With double shell and shrouded type closure systems the torque should be related to the inner component diameter.

1 wad thickness
2 container and thread starts
3 compression of any wad or wadless feature.

Multi-start versus single start threading

Multi-start threading, as usually found on lug systems and vacuum packs, generally provides more even pressure on the wadding or sealing media. Four start systems, for example, only need 90° or turn to remove and have threads or lugs of a steeper helix angle. Such systems rely on the vacuum for effective cap retention, as the steeper helix angle would make loss of torque (backing off) more likely, if only the interlock were involved. The vacuum is normally achieved by a hot fill or a steam headspace flush.

As mentioned previously, closures based on a single start thread may tilt or apply an uneven pressure if the turn of thread engagement is half a turn (180°) or less, except when such patented systems as Link-lok and Nek-lok are employed. The latter systems have a wedge-shaped bulge which is added to the container thread and/or closure thread at, say, 90° intervals under the container, or on top of the closure thread. These tend to centralise the cap on the container finish, thereby reducing or avoiding tilt. Such systems may also assist in closure retention and reduce loss of torque. There are other exceptions where a cap with half a turn engagement may be satisfactory, i.e. where used on solid products (thick ointments, solid paraffin-based products) which cannot suffer leakage and need virtually no special protection.

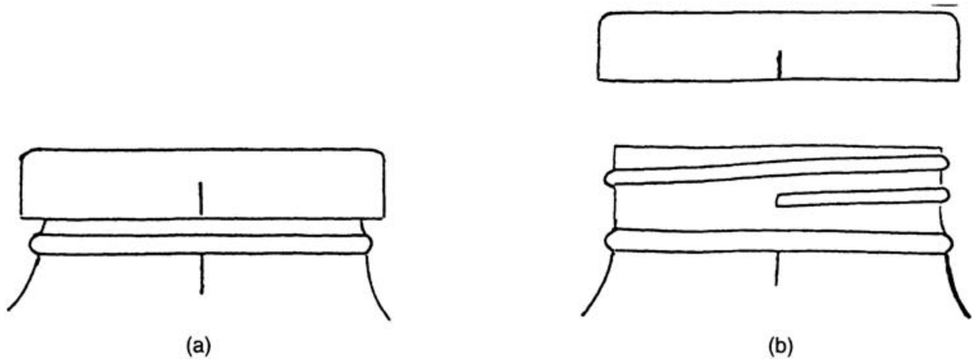

Figure 11.4 (a) Cap and shoulder marked; (b) unscrew cap with lifting, i.e. one complete turn

British Standard 1918 lays down the standard for the R3/2 (shallow), R4 (deep) and R4 (medium deep) threaded container finishes for glass or glass-like rigid containers. Standards for closures only exist by the fact that they are made to match a container finish. (For US equivalents, see Appendix 11.7).

British Standard 5789 1979 applies to plastic containers and closures requiring a buttress-type thread.

Thermosetting caps are compression moulded on either platen or rotary-type equipment. Pressure, dwell time and temperature are critical to the curing operation, otherwise brittle or soft caps may be produced.

Thermoplastic caps are invariably injection moulded. Extra decorative effects can be added by blocking, embossing in the mould, inserts and metal vacuumising. Plastic caps can also be printed by hot foil stamping or a process such as Tampoprint/ Padflex. The cost of laying down injection moulds is usually high, probably £800–1,500 per single cavity, depending on the number of mould components. The cost per cavity reduces if multi-impression tooling is employed, as does the cost per closure. Unlike metal, plastics can be moulded into a wide range of shapes and colours, thus adding to the decorative appeal of the pack. Double shell metal caps are also available, which give a smooth finish similar to a plastic cap.

Note that compo cork is recommended as the wadding for wide mouthed closures as it takes up any unevenness (undulations) of the sealing surface, or one can use a suitable grade of expanded polyethylene, particularly where glass is involved.

Other metal closures for glass and/or plastics

The foremost metal closures in this category are the crown closure (beer bottle) and the foil heat seal used for yoghurt pots, or the induction sealed diaphragm. The crown cork closure is basically a tinplate shell which contains a wad/facing. This may be conventional, polythene or a flowed-in compound. Its application is similar to the RO in principle in that top pressure is applied first, followed by application of crimping action. It is designed as a one use closure. Foil (and plastic) seals involve a heat sealing operation (see also diaphragm seals for pharmaceuticals).

Metal lever cap (narrow neck, mineral bottle)

Tinplate plus wadding. Can be resealed but is being rapidly replaced by Flavor-lok type closures.

Centre pressure cap

Tinplate plus wad. Press cap centre for cap removal. Press cap sides for retention. Used on glass jars but major use is on metal drums.

Metal vacuum seals

1 Top sealing disc plus rubber or plastic seal. This is held on by a safety band ring as used on jars of paste.
2 Light gauge aluminium cap incorporating a flowed-in gasket. The cap is crimped under the neck ring, i.e. jam, pickles, etc. Omnia (continuous beading) and Gerda (perforated beading).
3 More rigid closure usually made in tinplate applying a side seal on the neck by a rubber ring or flowed-in compound.

Note that certain flowed-in compounds can be used hot whereby threads or lugs can be moulded in from the heat of the container.

Other aspects of assessment

Although the effectiveness of a closure may relate primarily to the prevention of ingress and egress, many other aspects, as mentioned earlier, may be involved, such as the following.

1. Ingress and egress following use, i.e. can the closure be effectively reapplied and resealed (repeat earlier tests!) by all concerned? User assessment.
2. If closure system dispenses or assists in the administration of a product, does it do it effectively and reproducibly? (Query product contamination!)
3. Can closure be opened by the elderly, including those infirm, poor in sight, arthritic, etc. (and effectively reclosed)? Query age group.
4. Is the closure child-resistant,—i.e. has it passed BS 6652, 1989 or equivalent standard (US, ISO, etc.)?
5. Is the closure system tamper-evident, tamper-resistant? How can its effectiveness be established?
6. How can it be specified to give optimum on-line and off-line performance? What on-line performance is required? What quality standards need setting? How does it perform under compression and vibration (warehousing and transportation)?

Conclusions—reclosables

The total function of a pack relies on a successful marriage between the container and its closure. Over the years the role of closures has been extended and as a result the apparently simple act of putting a closure onto a pack has in certain instances become underestimated. Although the examples given in this chapter have in the main used screw-based systems, the principles offered for the assessment of closure efficiency can be applied to any design, i.e. push-in, push-over, etc. However, to achieve an effective seal, the design and the nature of the seal becomes dimensionally more critical. As in such systems at least one of the components (closure or pack) is likely to be plastic, the factors involved depend on the properties of both the container and the closure. In the case of plastics these variables include the moulding process, the type of plastic, the additives and processing aids included, moulding shrinkage, as well as the dimensional changes which occur according to climatic temperature and humidity variations. These all make the chance of ‘getting it right first time’ rather remote. The fact that many existing closure systems do have deficiencies, although unpalatable, has to be recognised. This should also make one aware that inventing any new concepts requires a series of trials and errors, evaluations and modifications, before the most effective compromise between container and closure can be achieved.

A final complication is the fact that closure systems (particularly those which assist in the dispensing or administration of a product) are becoming more complex and more sophisticated. The list which follows indicates many of the various closures and closure systems which are available for both primary and secondary packs: as seals or closures can be temporary or permanent, certain packs may have a series of closures created by the way in which they are converted or manufactured. A tinplate built-up aerosol container, for example, has four permanent seals, i.e. welded or soldered side seam, a cone and a dome held to the container body by double seams, a swaged-in valve cup, and an operational valve system (the in-use closure). Some of the systems will therefore be described in further detail.

1. Fold—overwrapping without sealing, fold over, fold down, grocer’s fold, roll wrap, bread wrap, etc. Note dead fold characteristic of soft foil (see BS 1133) and overwrapping, plus seal—i.e. heat, adhesive, etc.
2. Twist wrap—sweets, foil or special flexible cellophane or plastics where ‘twist’ does not unwind.
3. Bunch wraps—(also known as plunge wraps) where an item is pushed into a sheet and finishes with a pleated bunch, e.g. special soaps.
4. Ties—wire, paper—wire, plastic—wire, plastic for sacks, liners, bags. There are now a wide variety of locking plastic ties based on ratchets, loops, etc.
5. Adhesion with adhesives. Mechanical or specific adhesion to polar or non-polar surfaces (see below), e.g.

   - self-adhesive or pressure sensitive (cold sealing)
   - heat sensitive, or heat activated
   - PVA (polyvinyl acetate)
   - hot melt—100% solids
   - solder (lead and lead-free) and welding.

6 Heat seals and electrical sealing:

- direct and indirect heat sealing
- weld (melt)
- high frequency—radio frequency
- impulse, ultrasonic, laser, etc.
- induction etc.—see diaphragm seals.

7 Taping (plain and reinforced)—includes self-adhesive, water activated, heat activated:

- self-adhesive—usually plastic backed (PVC, polythene)
- cloths and laminated tapes—bitumen, foil, fibre, paper, etc.
- plastic tapes (polyester, HDPE, polypropylene).

8 Metal—nails, staples, screws, tacks for wood, fibreboard.
9 Strapping—wire, tensional steel, nylon, polypropylene, polyester.
10 String, thread and rope—stitching (sacks), tying using hemp, nylon, cotton, etc.
11 Taps (combined closure and tap)—tanks, drums, bag in box, etc.
12 Labels, tags and seals—destructible, non-destructible, water soluble, etc., may be used as tamper-evident features or a simple sealing aid, e.g. labels—paper+adhesive, pre-gummed, heat seal and pressure sensitive, plastic—self-adhesive.
13 Shrinkable sleeving and stretch sleeving, i.e. Viscose and PVC, PP, PET sleeving (items shrink by drying or heat). Stretch sleeving is usually based on polyethylene (LLDPE).
14 Foil—diaphragms, covers, lidding:

- heat seal—blister packs, moulded containers
- induction sealing—diaphragm and membrane seals.

15 Shrink and stretch wrapping—shrinkable films (PVC, polypropylene, polythene), sleeve or complete overwraps. Stretchable wraps, e.g. LLDPE, modified PEs.
16 Crimping—shaping, folding and crimping, e.g. collapsible tubes (metal). Aerosol valves for glass bottles. Overseals for injection vials.
17 Swaging—to shape with a swage (a die or grooved block for shaping). Aerosol valve in metal cans (1 inch orifice).
18 Tamper-evident and tamper-resistant closure systems. Tamper-evident closures, although seen as a specific group, offer a range of systems (see below).
19 Child-resistant closures—initially dating back to the Poisons Prevention Act introduced in the USA in 1970; cover both reclosable and non-reclosable systems—(see below).

Specific closures for containers (steel, tinplate, aluminium, plastic shipping containers)

1 Narrow neck (made in metal or plastic).
2 Press caps, screw caps, pourer taps, lever caps—orifices run from 28 mm upwards and may incorporate various pouring aids (e.g. spouts).
3 Full aperture—wide lug cover with sealing gasket, and ring locking system.
4 Fibreboard drums—slip lid/wide lug cover with sealing gasket.
5 Large aluminium containers—screw caps (plastic and metal)/bungs and plastic shives (antibiotics and perfumes)

*Collapsible tubes (two closures)—nozzle and base fold and cri*mp

Metal

1 Operational aperture (see Figure 10.3):

- blind end nozzles or metal diaphragm
- screw caps—thermoplastic—no wad (wadless) —thermosetting—wadded.

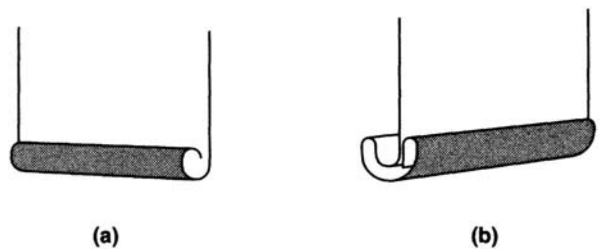

Figure 11.5 Metal closure

Figure 11.6 Double seam

2 Filling aperture (see Figure 11.5), shaping, followed by double 1 or saddle fold 2+ crimp. The seals may be improved by incorporating a heat sealable or pressure sensitive band in the fold area.

Plastic

1 Operational end. If pliable material, rigid wadless caps thermosetting or HD polythene, polypropylene, polystyrene. If rigid material, wadded rigid cap, or wadless pliable (thermoplastic) cap.
2 Filling end. Heat seal, heat weld with cooling jaws usually essential (avoid presence of product). Also ultrasonic welding, hot air sealing, plus cooling jaws, etc.

Metal cans and composite containers

General line type containers

- Lever lid (paint).
- Lever lid+diaphragm—tablets.
- Vacuum lid with flowed-in compound—boiled medicated sweets.
- Hinged lid—pastilles.
- Screw cap—metal or plastic.
- Rotary (plastic)—talc.
- Jay-Cap (thermoplastic), flip-cap.

Open top cans

Open top cans are either three-piece built-up cans or two-piece cans. These may have a ring (pull) tab on double seamed aluminium lid (beer). Key opening (sardines) on double seamed food can (ham).

Most cans have double seamed ends (compound lined); these use five thicknesses of metal, e.g. most food type cans and some solid pharmaceutical products.

A double seam gives a good hermetic seal (Figure 11.6).

Note that the closure or sealing of other seams may be overlap or joint, plus solder, single seam (dry, soldered or cemented or doped), welded. Soudronic welding (butt welded) is now replacing soldered side seams. There is also a preference for two-piece rather than three-piece cans.

Impact extruded aluminium cans

These were widely used in the UK for pharmaceutical tablets, powders, etc., but are now less popular in Europe and the USA due to cost compared with glass and plastic. Closures are plug (polythene), snap-on over bead (polythene), or metal screw cap fitted with conventional wadding or flowed-in compound lined. Extruded aluminium containers are still widely used for 10–30 ml monobloc aerosol cans.

Non-reclosables

Flexible packaging such as laminates, films, pouches and sachets relies on various styles of seal. These may be fin (inside to inside) from a single web, overlap (inside to outside) from a single web, inside to inside from two separate webs (four sided seal), or one web folded over by a centre fold (three or four sided seal).

The sealing may be achieved by heat involving temperature, dwell and pressure, together with removal of heat (while seal is under compression), with adhesives, or cold pressure sensitive sealing. Seals may be permanent, semi-permanent or peelable. Heat sealing may use direct (contact) heat, using a nitrocellulose, PVdC, heat seal coating, etc., or by indirect welding (hot air), using polythene (LDPE, LLDPE, ULDPE). The source of heat may also be created by ultrasonic, radio/HF welding, impulse, induction, laser, etc. Seals can also be achieved in certain cases between two different materials—i.e. melted or softened polythene will adhere to paper or board. In some circumstances two different heat sealants can create a peelable bond.

Note that although many films, laminates, etc. may have a 100% effective seal, the materials employed may be permeable to moisture, oxygen, carbon dioxide, etc. This property can be either a disadvantage or an advantage, e.g. plastic film overwrap can permit sufficient moisture permeability to cause a product to reach its critical (unacceptable) moisture level. Hence a laminate (without a foil ply) is not a hermetic pack.

The seal layers may be actual films, coatings or sealable lacquers quantified by caliper, i.e. micrometre or coating weight as g/m^2. The same base material may be used in a range of coating weights depending on the combination of the plies used, whether sealing mechanism is by platen or rotary sealing and the machine speed. Coating weight or caliper and the question, ‘what is best?’ are usually a trial and error exercise. What is best for one machine may not be ideal for another.

The sealing of non-reclosable materials, although predominantly reliant on heat sealing, involves other methods of sealing such as solvent, adhesive, cold sealing. These share a number of factors, including seal width, properties of the materials, cost, etc., with heat sealing remaining the most complex of the likely sealing processes. The following gives an indication of the other factors that may contribute or need consideration.

The properties of the materials of construction

Materials may be single or multiple layer. The latter may incorporate plies which provide strength (support plies such as paper, or tough, difficult-to-tear materials such as nylon or polyester), cushioning (paper), a barrier to gases, moisture, light, optimisation of cost (density, yield—basic cost, etc.), good printability, an ability to seal in the presence of contamination, etc.

The conversion process used to create material

Extrusion, lay flat tubing, calendering, casting, solvent or aqueous dispersion coating, etc. for single layer materials. Multilayer processes—wet or dry bonding (lamination), extrusion coating, coextrusion, etc.

Properties specific to heat sealing

Caliper, coating weight, softening, melting point, sealing range, viscosity, hot tack, ability to seal in the presence of contamination.

On-machine performance

Throughput, speed, possibly as metres per minute, how sealed by platen or rotary principles, how cooled and cut. Release following seal compression (jaw release)—depends on seal design, cleanliness of jaws, surface characteristics of materials, possible buildup from lacquers, varnishes, surface pick, pressure of inks, etc. External temperature applied and conductivity through to seal layer, cooling and cooling interfaces (air-metal, metal-metal and heat sinks), etc.

Reel factors (or sheet factors)

Width, diameter, core size, flagged joins (number permitted), maximum weight (handling by hand or mechanically), friction-slip characteristics (static build-up). Tightness of winding.

Storage factors

Type of storage position, i.e. normally flat, not on diameter, storage conditions, advised storage life—re-examination period, possibility of blocking.

Transportation factors

How handled, protected and packed. Position of travel.

Seal pattern

There is a diversity of seal patterns, i.e. flat smooth seal (no pattern), line pattern—all in same direction or at right angles, cross hatch or pyramid type patterns. Single (one-sided) or two-sided matching patterns. Seal pattern may encourage easy opening (tearing) or make opening difficult so that a propagation point is essential.

Width of seal

Seal width may be as low as 3 mm (small blisters), with 5 mm an advised minimum for sachets and strip packs. Width depends on web wander (a 10 mm width may be used where web wander may be ±5 mm, i.e. seal can be 5–15 mm.)

Design of pack

Pack design has to consider product volume, size/shape and weight and the seal width required to restrain/retain product. In certain processes, i.e. strip packs, flow packs, where the item actually extends the pack virtually at the time the heat (or cold seal) is being applied, the internal area must be large enough to prevent excessive pressure on the seals (thereby leading to stress, possible creases and capillary channels in the seals, or actual material perforation).

Material expansion and contraction during sealing

All materials expand or contract when heat is applied. If the web uses different constructions of materials each side, one is likely to expand more than the other, e.g. sachets using clear material one side and opaque the other. Whether this expansion and contraction lead to stress will partly depend on whether the full webs are subjected to heat or just the seal areas. Certain blister configurations suffer from tray curl, thereby making a cartoning operation more complex.

Heating methods and cooling

Heat may be applied by direct (e.g. contact heat) or indirect methods (e.g. hot air). Whatever the method of heating, the bonding materials must reach a specific minimum temperature for each combination of materials to weld together on cooling. This temperature is normally achieved by applying a much higher temperature to the surface. The transfer of the applied heat depends on the conductivity of the materials, the dwell time and the pressure. The strength of the seal made immediately after the heat is applied depends on the hot tack property of the heat sealing material (s). Although the seal can be improved (or achieved more rapidly) by cooling, hot tack is responsible for the initial weld or bond.

Hot tack varies between materials, increasing as follows:

LOW ⟵⟶ HIGH

Wax   Hot melt   LDPE   LLDPE   EAA   Ionomer

ethylene copolymers

Cooling therefore is more critical to the materials showing low hot tack and may be achieved by air (cooled), water or chilled water.

The combination of temperature, dwell time, pressure (and cooling) will also depend on whether the sealing processes are platen or rotary, and whether the web is only heated at the point of seal or is preheated. As rotary invariably gives a tangential pressure between two cylinders, the dwell time is extremely short, thereby demanding a higher temperature than that used in a platen process for the same material, even when preheating is employed.

Temperatures at which heat sealing occurs generally range from around 75 °C to 240°C. The list below goes from those sealing at a relatively low to high temperatures:

- (low) hot melts
- EVA
- ionomer
- lacquers
- LDPE
- LLDPE
- HDPE/PVdC
- (high) PP.

Heating or 'heat sealing' can also be achieved by impulse, ultrasonic (beware particle generation), induction, radio or high frequency, electromagnetic, vibration or laser methods.

Seal types

Seals may be permanent, semi-permanent, or peelable. Peelable systems usually consist of ethylene copolymers, possibly modified with polyethylene, or other films, lacquers or dispersions. Some are resealable, hence are not strictly tamper-resistant. Cold seals, typically based on a rubber latex, are usually non-resealable. These may employ the cold seal only in the area of the seal, hence avoiding any or limited product contact. Pattern systems are widely used for surgical materials and instruments.

Trimming and cutting (guillotine, die cut, scissors, shears, etc.) and perforating

As most heat sealing activities are based on reel-fed materials, cutting or trimming is an essential part of the overall process. Whether a material can be effectively cut depends on the cutting process, the material (metal) employed, how the web is held or restrained, the properties of the material(s) being cut and the temperature of the material when being cut, etc. Under certain conditions the cutting edges may blunt faster or give a poor cut. This also applies to perforation.

With die cutting this may be done by platen (intermittent process) whereby the web is stopped, or rotary (continuous motion). The latter process is considerably more expensive.

Ease of opening

Ease or difficulty of opening depends on the properties of the materials, the design and seal pattern. Polyester, Nylon and polypropylene may give rise to difficulties, hence it may be necessary to incorporate a propagation aid feature such as a V-shaped notch, a cut or slit. The other alternative is a peelable seal. The seal strengths of permanent and peelable seals are measured by a similar process.

Tamper-evidence, tamper-resistance and child-resistance

In general, heat sealable packs are not resealable once opened, hence they are inherently tamper-evident and tamper-resistant. Certain cold seal materials may be resealable, hence they do not comply with this parameter. Child-resistance properties are less easy to confirm, as the standard varies between countries. In the USA materials have to meet the test created via the PPA (Poisons Prevention Act 1970), in Germany DIN 55559, and the UK BSI 7236 1989.

Cost

Cost depends on the complexity of the material (especially multi-ply) and the yield. In terms of the heat seal ply cost, these are likely to increase as follows

$$\text{LDPE/LLDPE} \longrightarrow \text{EVA} \longrightarrow \text{EAA} \longrightarrow \text{ionomer}$$

and according to the caliper/coating weight, and the means by which they are applied (i.e. adhesive, extrusion, aqueous, or solvent coated).

Other factors

To the above can be added a few other rather obvious factors, i.e. non-blocking, nonexuding, non-tainting, with the correct slip/friction properties. State of the material surface, particularly with reference to oxidation, may also influence a heat sealing operation. This may be derived from a conversion process (e.g. pretreatment for printing). Other processes such as used to render a material sterile (e.g. gamma irradiation, steam sterilisation) and any surface active agents incorporated as additives or processing aids may also cause heat sealing problems.

The above still only covers some of the factors associated with a heat sealing operation. The primary factors remain: temperature, dwell, pressure and cooling.

Membrane or diaphragm seals

Although there are mixed views on membranes or diaphragms as a tamper-evident feature in that they are not visible until the closure is removed (i.e. not visible at point of sale), they do offer positive seal potentials. Diaphragms can be affixed to a container by adhesive, by a direct heat seal or by a pressure sensitive adhesive sealant. In the pharmaceutical industry the fourth method, induction sealing, has general preference. This involves a foil membrane coated with various plastics, which is retained in the closure and then subjected to induction (or eddy currents) after it has been applied to the container. At this stage, the induction head, which contains a water cooled copper coil, creates an electromagnetic field thereby inducing a current in the foil and producing an almost instantaneous heating effect. This heat seals the plastic facing attached to the foil onto the container neck and melts a layer of wax which retains the secondary liner in the cap when the foil seal is broken. Retightening of the cap is normally advised following induction sealing.

Various induction heat seal liners are available, such as the following.

1 On activating, the material separates to provide a foil seal with a pulpboard liner in the cap as a reseal.
2 Where pulpboard is inadequate (e.g. with liquids), a polyester faced liner on the pulpboard may be employed with a paper covered foil membrane.
3 This may involve a one-piece liner where the whole material forms a diaphragmtype seal. The diaphragm can be cut with a tab feature to aid removal.

Surlyn ionomer is the more widely used material. Seals can be achieved to LDPE, HOPE, PP, PET, PVC, PS and SAN.

With glass the contact ply depends on whether the glass is treated or untreated and whether the product is dry or wet. In certain circumstances special treatments may be necessary to give either a weld or peelable seals.

Membrane or diaphragm seals can provide very effective seals. This can be particularly important with plastic caps on plastic bottles which suffer loss of torque with the lapse of time. In these instances, the diaphragm provides an effective seal up to the point of use, after which the cap takes over the closure function.

Adhesive sealing

Adhesion is basically the joining or bonding of two materials by a third material. There are two primary methods of adhesion, physical or mechanical adhesion and chemical or specific adhesion.

Mechanical adhesion, as the title implies, is achieved by the open or porous nature of the substrate(s), whereby the adhesive penetrates into the cracks, crevices or gaps in the surface(s) involved. Specific or chemical adhesion involves the bonding of nonabsorbent or non-porous surfaces such as found with glass, metals, including foil, and plastics. The bond achieved between these materials and the adhesive depends on molecular or electrical forces based on van der Waals' forces. Polar and non-polar materials need to bond with like adhesives.

Types of adhesive

There are three basic types of adhesive:

1 solution adhesives where the adhesive constituent is dissolved in a carrier (e.g. starch pastes, dextrines and contact cements such as polystyrene cement) or solvent
2 dispersion adhesives where the adhesive component may be as a dispersion, suspension or emulsion, e.g. polyvinyl acetate emulsion
3 hot melt adhesives which are made from 100% solids based on blending hot liquid thermoplastics which can be reactivated by heat.

Terminology associated with adhesion

Phrases that need to be understood include the following.

- Viscocity—resistance to flow.
- Wetting—the ability of an adhesive to flow and wet a surface by coming into close contact with it.
- Tack—the ability to form a bond of measurable strength immediately after the adhesive and adherent have been brought together.
- Setting time—the time needed to form an effective bond by mechanical or specific adhesion, e.g. a fibre tearing bond with paper-based materials.
- Open time—the elapsed time between the application of the adhesive to one or both substrates and the bringing together of the two surfaces to give an effective bond.
- Drying time—the time elapsed to form the final bond.

According to the circumstances, e.g. hand applied versus high-speed machine applied adhesive, the above factors will vary significantly. Hand applied operations normally need a longer open time, lower tack and longer setting time than machine applied, which requires a short open time, with high tack and a rapid setting time.

Classification of adhesives

Although there are many adhesives, there are only four main adhesive classifications, i.e. animal, vegetable, mineral and synthetic.

1. Animal glues are usually made from bones and hide. Casein from milk and fish glues are also of animal origin.
2. The main vegetable adhesives are based on starch and dextrine; the latter is a modified form of starch. Each has wide applications.
3. Mineral based adhesive systems involve materials such as sodium silicate but use of this, particularly for fibreboard, is reducing. Bitumens, asphalts and pitches could be put under this category.
4. Recently, synthetic adhesive systems have steadily increased based on synthetic rubber latices, polyvinyl acetate dispersions and hot melts, etc.

Factors influencing adhesion efficiency include the following.

1. Wetting out—the ability to create a continuous film (there are exceptions, see hot melts) which depends on both the adhesive and the substrate.
2. Viscocity—the resistance to flow. Adhesive must have good flow properties to achieve adequate coverage and uniformity of film thickness.
3. Polarity—like will bond only to like. Hence a polar surface needs a polar adhesive and a non-polar surface a non-polar adhesive. Both paper and wood are polar materials.
4. pH control, i.e. acidity/alkalinity extremes—unless controlled, the acid or alkalis could interact with material substrates, e.g. metal, causing corrosion or weakening of the bond.
5. Cleanliness—the presence of contaminants such as grease, dust, dirt can reduce adhesive-adherent contact, hence weaken the bond.
6. Microbial growth—certain adhesives (starches, dextrines) can support microbial growth, hence either preservatives will need to be incorporated or procedures used to minimise microbiological contamination.
7. Stress—adhesive film must be able to withstand stresses due to moisture (loss/gain), deformation from creep or cold flow, differential expansion and contraction, etc.
8. Adherent surface properties—ideally surface should be flat, smooth and not too porous.
9. Temperature—of adhesive and adherent at point of and immediately after a bond is made.
10. Water resistance or solubility—adhesives may be required to be water-resistant or water-soluble. This may influence bond quality and ultimate removal for material reuse, recycling, etc.

Methods of adhesive application

Adhesives may be applied in several ways, as follows.

1. Brush—a well-established method for hand application, but slow and variable consistency.
2. Dauber applicators—simple method of transferring an adhesive to a stationery area by a coated bar, finger or plate.

3 Wheel or rotary cylinder—the wheel or cylinder picks up adhesive from an open pot, tray or bath. This is thinned by a doctor blade or transfer roller system. The thinned layer is then transferred to the substrate. Viscocity properties are critical.
4 Low-pressure extrusion—via a nozzle head or die fitted with an on/off valve system.
5 High-pressure extrusion i.e. jetting—widely used for hot melt systems where a jet is 'fired' by a pressurised gun.
6 Spraying—similar to jetting except that adhesive is broken up into finer particles. Since this partially dries the adhesive, higher output speeds may be derived from this process.

Adhesive usage

Usage for adhesives is rather like horses for courses. Certain ones find very traditional applications. Animal glues are, for example, widely used for bookbinding, tube winding, including fibreboard, and for the production of so-called gummed tapes. Casein finds a specific application for bottle labelling where the product is chilled (e.g. beers and carbonated drinks) and there may be a film of moisture on the container. Casein has also been used in foil laminations. Mineral glues, and in particular sodium silicate, have been used for tube winding, corrugated board and the lamination of fibreboard. Sodium silicate's use is slowly reducing, partly due to the fact that it has high alkalinity. Bitumen is still used as a waterproofing layer in union Kraft type combinations. It can be applied as a hot melt or as emulsions or solutions in organic solvents. However, the use of solvents in any application is becoming less favoured. Vegetable adhesives still find extensive applications. Various types of starch are still used as a lap paste in wrap-around can and bottle labelling. Borated and unborated dextrines are used for envelopes, carton and case sealing, tube winding and bottle labelling. Vinyl-dextrines are used for remoistenable coatings.

In the synthetic category can be included dispersions and suspensions (but frequently called emulsions) which can be used on more difficult substrates where specific adhesion is essential (plastic, metal). They have a wide range of uses which include pressure and heat sensitive based materials. Various polymer systems are found based on both thermoplastic and thermosetting adhesive systems, e.g. vinyls, acrylics (increasing in use), polyamides, polyurethanes, ethylene vinyl acetate, vinyl acetate, ethylene acrylic acid (EAA).

Modern Plastics Encyclopedia lists the types of adhesive system which may be used to bond together similar and dissimilar plastics. These are usually coded under elastomeric, thermoplastic resins, thermosetting resins and miscellaneous systems.

In addition to adhesive, plastic components can be directly joined together or sealed by several techniques as described earlier.

Hot melts are 100% solids and can be formulated from a range of plastics to give various levels of tack with a range of setting times. Their benefit lies in cleanliness (no solvents or solutions to drive off), ease of application, short open time and fast setting times. They can also be used to seal virtually any substrate with the availability of good climatic properties from deep freeze to high tropical conditions. They are very resistant to water (waterproof and permeation).

Cold sealing

The use of cold seal adhesives, frequently laid out to a pattern (e.g. pattern lacquered), is becoming increasingly popular in the confectionery industry, particularly for flow wraps. Most cold seals are emulsion-based rubber latex systems applied by a gravure print roller. They have the advantage, as pressure sensitive systems, of achieving much faster sealing than conventional heat sealing. Some use is now being found for pharmaceutical application.

Closure evaluationÐintroducing new methodology

Methods for leakage detection are becoming increasingly complex in terms of instrumentation, with a trend, certainly for production packs, towards non-destructive testing. However, even so-called non-destructive tests may have conflicts with GMP.

Summary of leakage detection

Leakage (egress and ingress) can be related to liquids, solids, gases including bioburden and the methods associated with their detection. The list below includes those already mentioned together with others which have been or may be employed.

Observation of visual defects, e.g. pinholes, capillaries.

Vision systems could be included under this heading—see also 'Visual inspection systems' below.

Weight change

Loss or gain versus time under specifically defined conditions (and by chemical analysis).

Pressure—vacuum changes

By the application of pressure and/or vacuum under defined conditions (including fluctuating conditions), e.g. leakage by ingress/egress of external atmosphere or internal contents. This may involve the release of gases, e.g. air as bubble-type tests—limits of detection by visual inspection are usually around 1 cm^3 per minute with the 'possible' detection of pinholes down to 20–25 μm. Tests involving immersion in water may be carried out with or without wetting agents (to lower surface tension) and dyes.

Pressure decay systems normally operate to a specified pressure (usually within the pack) which is then monitored for pressure drop. Leaks down to 10^{-3} cm^3/s can be detected. There is also a pressure increase method where leakage from a pack under vacuum can be detected as a positive pressure change (assuming an excellent vacuum chamber seal is achieved).

Certain flexible packs will extend or indent (i.e. undergo deflection) according to whether a pack is under vacuum or pressure when well sealed. A grossly leaking pack will show virtually no movement, and a slightly leaking pack less movement, than a well sealed pack. These movements or deflections can be quantified, e.g. by differential pressure, transducers (capacitive type) or spring loaded sensors. Typical instruments include the blister testers which sense deflection and, with larger packs (e.g. sachets), detect 'force' changes. Both these instruments are considered more sensitive than the older conventional vacuum with dye tests as pinholes down to 10 m can be detected. These tests also have the advantage of being non-destructive.

In most instruments based on the above, the test period is kept to a short time (e.g. 0.5 to 1.0 s) so that temperature influences are minimised. It is also important to restrict creep, as certain materials will extend under unfavourable conditions.

Gaseous detection tests

These may use a specific gas associated with the product or a gas which can be specifically introduced for the leakage detection process, such as the following.

- Helium (sniffing) currently uses mass spectrometry which enables leakage to be detected down to 10–12 Pa m^3 s (this test can demand a high vacuum which may not be ideal for the component being tested). Certain halogens are also used for gas detection.
- Oxygen, i.e. Mocon Ox-tran—uses a stream of dry nitrogen whereby oxygen is detected coulometrically.
- Carbon dioxide, e.g. Mocon Permatran C detects carbon dioxide in another dry gas by infrared.
- Moisture vapour, e.g. Mocon Permatran W or Dynamic water vapour tester measures moisture by a photoelectric sensor.
- Radio isotope tracer gas, e.g. using krypton 85 where a high sensitivity is reported.

Burst tests

The strength of the seal on flexible packs (achieved by cold and heat seals) can be quantified by tensile tests as seal or peel tests or the air pressure required to create rupture of the pack. This can be carried out by a hypodermic needle arrangement followed by pressurising the pack at a specific rate until the pack bursts. Depending on the nature of the seal, the point of rupture may arise either in the body of the pack or the seals. An alternative method is to place the pack in a jig followed by a steady mechanical increase in compression.

Microbial integrity

Various procedures have been developed (under normal pressure and vacuum) to check whether highly contaminated liquid, gel or media based material will grow back or penetrate closure systems. Variable results suggest that alternative methods to detect leakage are preferable.

Crack, pinhole, capillary detection

Conventional dye/vacuum immersion tests were widely used to check the seal efficiency of ampoules. These have largely been replaced by electrical conductivity and capacitance type tests. Typical equipment includes the Nikka Densok ampoule inspection machine which employs a high frequency and high voltage. This distinguishes between good glass (which is a nonconductor) and areas of cracks or pinholes where current will flow between the inner and outer glass surfaces. Other machines use the principle of capacitance and dielectric constants, where a material with defects (penetrating cracks) will show a higher dielectric constant.

Thermal conductivity

These use a thermistor bridge which is balanced against air and is subsequently upset if another gas leaks into the air.

Chemical tracer tests

Used with materials which can be detected by interaction, i.e. ammonia on one side, hydrochloric acid gas on the other (formation of white cloud of ammonium chloride indicates transfer and leakage). This type of test has been used for pinhole detection.

Thermocouple gauges

Mainly used to detect a drop in temperature when solvent-type systems escape under vacuum. Could also be used to detect the presence of a warmer gas.

Physical or mechanical assessment procedures

These involve the widest variety of factors, e.g. screw caps are controlled by application torque and by removal torque. However, these change according to material, design, environmental factors, etc., some of which may never have been fully investigated. This equally applies to any closure system which relies on compression, interlocking, interference forces, etc. in order to make and maintain a 'seal'. Thus, although certain forces can readily be measured, e.g. torque, force to push in a plug, pull out a plug type system, force to apply or remove a press-over closure. The variables associated with most of these systems (see the appendices) tend to be quite horrific. Whether the measured forces equate with an effective seal will vary according to the quality of the materials employed and the perfection/imperfection of the surfaces involved between the two interfacing materials.

Some excellent work has been done in this area by Dr Dana K.Morton of Schering Plough, USA, who investigated the seal integrity of rubber capped vials using a range of techniques, types of vial (blown and tubular) and a range of coated and uncoated rubber components. This work concluded that control of (top) rubber compression, quantified as residual seal force measurement, could be correlated to seal integrity in terms of liquid, gas and microbial factors, measured in Pa m^3/s.

The West Company offers two pieces of equipment to check rubber-vial type closure systems, i.e. the Seal Force Tester, which quantifies residual compressive forces, and the Seal Force Monitor, which checks the forces applied during the capping and sealing operation.

Visual inspection systems

Visual (imaging) inspection methods are gradually replacing the previous human inspection where each unit was individually viewed (frequently under two times magnification) against a white or black background. Although not currently bearing a direct assessment of closure integrity, they can eliminate likely suspect packs.

Note that 'leak-tight', as defined by NASA (Aerospace), is when nitrogen at 300 psig leaks at a rate not greater than 1.4×10^{-3} cm^3/s. It should also be noted that the pressure exerted by a gas will change according to the temperature (Charles's law). This roughly means that a 1°C rise or fall will change the test pressure, up or down, by approximately 0.4%.

Special aspects of closures and their assessment

Closure systems are becoming more complex and sophisticated, incorporating features related to such aspects as tamper-evidence, tamper-resistance, child-resistance, special easy opening closures for the elderly, and product administration.

Tamper-evidence and tamper-resistance

The earlier use of the word 'tamper-proof' has been replaced by tamper-evidence and tamper-resistance. The Extra Strength Tylenol incidences between 29 September and 7 October 1982 in the USA, whereby seven people were killed by cyanide and the copycat poisonings which followed, provided a worldwide alertness to the issue. Although TE/TR cannot offer total security it does offer some assurance that the product has not been contaminated, some of the contents removed and possibly replaced (e.g. watered down), etc. Certain TE/TR features (sealed diaphragms, ratchet closures) also improve overall closure efficiency in that cap backing-off or loss of torque is likely to be less of a problem.

Definitions of TE/TR are as follows.

1 Tamper-evidence (TE)—'if breached or opened, package will provide visible evidence that the said container or package has been tampered with'.
2 Tamper-resistance (TR)—'that which creates a barrier to entry and has to be broken or removed before entry can be achieved and which is difficult to repair (if necessary) without leaving any evidence'.

In the UK the current types of pack which are considered to fall in the TE/TR categories are as follows (note the preference in the UK for the term 'security packaging').

1 Film wrappers—a transparent film wrapped securely around a product or product container. The film must be cut or torn to open the container and remove the product.
2 Bubble packs—the product and container are sealed within a mount or display card generally composed of card and/or plastic.
3 Shrink seals and bands—bands or wrappers shrunk by heat or drying to seal the union of the cap and container. The seal must be cut or torn to open the container and remove the product.
4 Bottle seals—paper or foil sealed to the mouth of a container under the cap. The seal must be torn or broken to open the container and remove the product.
5 Tape seals—paper and/or foil sealed over all carton flaps or a bottle cap. The seal must be torn or broken to open the container and remove the product.
6 Breakable caps—the container is sealed by a plastic or metal cap that either breaks away completely when removed from the container or leaves part of the cap attached to the container. The cap must be broken to open the container and remove the product.
7 Sealed tubes—the nozzle of a tube is sealed and the seal must be punctured to gain access to the product.
8 Sealed carton—all flaps of a carton are securely sealed and the carton must be visibly damaged when opened to remove the product.
9 Sealed units—dosage units individually sealed in foil, paper or plastic pouches, where the individual compartment must be torn or broken to gain access to the product (e.g. strip, blister and sachet packaging).

It should be noted that this follows the list approved by FDA regulations on 5 November 1982. However, since that time the USA has withdrawn the use of glued cartons, cellulose shrink bands and heat sealed (folded) overwraps based on the fact that some can be opened and resealed.

Child-resistance

The advent of the Poisons Prevention Act 1970 in the USA formally introduced childresistant packaging. The Act required both reclosable and non-reclosable (blister, strip, sachet) packs to pass virtually the same test procedure if child-resistant properties were to be claimed.

BS 5321 1975 for reclosables basically followed the USA protocol. No equivalent standard for non-reclosables was introduced, as the Medicines Commission (1974) believed that blisters and strips were reasonably child-resistant and were concerned if large numbers of children were involved in testing procedures. BS 5321 has now been replaced by BS 6652 (see also ISO 28317) 1989 which permits a sequential sampling procedure of up to 200 children between the ages of 42 and 51 months, thereby allowing a closure to be passed or failed with the involvement of smaller numbers of children. UK approved reclosables include Poplok, Clic-lok, Tracer, Snapsafe, Squeeze-lok, Push-lok, Medi-Loc.

UK legislation currently covers aspirin-and paracetamol-based products and a series of household/chemical products introduced from 1 December 1987. For solid dose dispensed medicines there is a scheme which requires pharmacies to use child-resistant systems unless they are not required by the patient (i.e. elderly, arthritic, infirm, etc.). Child-resistant closures are also required on certain liquid products.

Child-resistance, tamper-evidence/resistance and OPD (original pack dispensing)

Blisters and strips by their design are inherently both tamper-evident and tamperresistant. Although the Medicines Commission report of 1974 suggested that blisters and strips had child-resistant properties, positive evidence of this did not clearly emerge until Glyn Volans *et al.*'s reports appeared in *Human Toxicology,* July 1987. These reports indicated that both reclosables which had passed BS 5321 (now replaced by BS 6652 1989) and opaque blisters and strips had reduced poisonings when compared with non-approved or conventional reclosable systems. As a result of these reports the PAGB, with the support of the ABPI, produced 'Design Guidelines for Strip and Blister Packs (1987)', which basically eliminates any 'flimsy' blister or strip packs which may be questionably child-resistant. This document later became BS 7236 1989. As a result, blisters and strips which meet the guidelines were at one time termed to have 'child-safe' properties rather than being called child-resistant.

It should be noted that the Medicines Commission did not advise a test procedure (such as BS 5321) for blisters and strips since the variety of configurations and product sizes could have exposed a significant number of children to the challenge (and learning risk) of opening packs. Although the USA has always used the same test for reclosables and non-reclosables, this is questionable since an opening of a reclosable can expose a child to larger product quantities compared with the single opening of blisters and strips. Non-reclosables also offer another obstacle in being available in small quantities, and children may tire of repetitive activities. There is also a risk with a reclosable that the previous user may not have resealed the pack correctly. The Volans report therefore goes part of the way in challenging the use of the US protocol for blisters and strips. The BGA in Germany is, however, meeting the US protocol by a 'type test' which approves a material for any blister/strip configuration, product shape/size, etc. based on one test. The materials approved include perforations between blisters, a tissue/foil/heatseal lidding material and a range of other combinations. The children at the greatest risk fall into the 2– year age group which is not covered by the US protocol, hence using children of 42–51 months could be equated with an accelerated test. The ISO standard ISO 8317 has been approved for reclosables, but a standard for non-reclosables is still under debate. German standards for type approval are based on DIN 55559.

Packs for the elderly, including monitored dosage systems

The improved security and integrity achieved by certain closure systems make them more difficult to open (and reclose where relevant) for a growing elderly population. The fact that these people survive longer because of their medication will require increasing attention in the future. To assist in this, various compartmental-type packs (e.g. larger blister) have been developed so that all the medications required for a set time (e.g. 8.00 a.m., 12 noon, etc.) can be placed in special compartments. Although this placing of various products with each other was initially approved by the Royal Pharmaceutical Society for the short period involved (1 to 4 weeks' supply), pharmaceutical manufacturers would be concerned if interaction risks arose under the terms of 'product liability'. Whether the products need testing (a) for the short periods and (b) in contact with other likely products is now under debate as to whether any 'risks' need quantification. These new types of pack, classified under the heading, 'monitored dosage systems', tend to conflict with the concept of OPD, as bulk packs are required for economical transfer to the new packs. Other systems such as MEMS (medical event monitored systems) either record when medication is taken or alert the patient when to take the medication, and are also becoming more available.

Closure systems involving product delivery or administration

Historically some of the first closure systems to include dispensing features were those used for drops, those incorporating an applicator (e.g. corn solvent) or brush (paints), and atomiser sprays. These were followed by the more complex valve systems subsequently used for a wide range of aerosols. It was the era of thermoplastics that introduced the complexity of closure systems found today, starting with dropper plugs and spray systems invented and commercialised in the early to mid-1950s. Since that time closure systems involving product delivery have steadily increased. These now include such items as prefilled syringes, IV packs, a wide range of pump systems, and valves, etc.

Since most of the above have an additional role to play during the period of use, assessment of performance during use requires thorough evaluation. In the case of multiple dosage packs, this involves checks for uniformity of delivery, malfunction (sticking, blocking, microbial contamination, etc.), degradation/loss of potency during the whole period of use with and without extended periods of storage involving any likely misuse or abuse by the user. As product particle size has become more critical, particle size analysis is now essential to certain performance evaluations. Compliance associated with the instructions and the device also has to be assessed.

Since in many of the newer administration systems the pack and closure cannot be segregated it is perhaps useful to look at a likely total testing schedule. Defining the type of test which may be required will depend on the types of material involved, i.e. glass, metal, plastics, etc.

However, as packs become more complex and more innovative, plastic becomes the more favoured material for sound economic reasons (frequently associated with fewer components which provide simpler assembly procedures). Any testing schedule may be influenced in the final level of intensity by various additional factors, the route of administration and the risks associated with it. This normally places IV solutions and injections at the top of the 'risk' list, i.e. those at the top of the list demand the greatest intensity of evaluation. For more details see Chapter 8, Appendix 8.8.

Compliance and confidenceÐconclusion

It should be evident that if the user, patient, or professional administrator of the product has confidence in the product and its pack, the likelihood of 'success' and compliance can be enhanced. Evaluating this feature by market research, questionnaires during clinical evaluation and consultation with the professionals who handle the product—pack (doctors, dentists, nurses, pharmacists, etc.) will become more vital in the future. The user-patient, in being made more aware of packaging, frequently in a negative environmental cost-effective role, may also become more critical of pharmaceutical packaging. This will lead, in the long term, to more effective packaging and better instructions on how the product should be used.

Seal integrity has now reached a status of greater importance under the terms of GMP and the fact that recalls related to seal failure regularly occur. In addition to this the broader role of the pack places increasing demands on the closure, particularly at the point of use.

Appendix 11.1: Leakage detection in sterile products

It has been widely accepted that compendial tests for sterility do not give high confidence that sterility is both achieved and maintained. Starting with a low (controlled) bioburden, maintaining GMP which builds assurance into the processes, adequate validation, and effective closure systems are the essential prerequisites to satisfactory sterile products. These basic principles apply irrespective of whether sterility is achieved by an aseptic or a terminal sterilising process. Checking that the closure system is effective in preventing microbial contamination or recontamination is critical to both unit dose and multi-dose products. Many papers have investigated this subject related to ampoules, IV solutions, multi-dose vials, syringes, etc. Examples of some of these papers are listed in Appendix 11.2.

Ampoules

At one time, 'ampoules' was synonymous with glass as either single or double ended systems which were produced from tubular glass. Although glass ampoules are still widely used, plastic ampoules usually made by a form or blow fill seal process (Rommeleg or Automatic Liquid Packaging) have shown a steady growth. Although the principles of manufacture and sterilisation (predominantly terminal versus predominantly aseptic) are different, both are sealed by a welding/fusion process and tests are therefore required to check the integrity of each (see above).

Vials

Rubber-based closures have a good chance of flowing into minor imperfections and making an effective seal provided there is adequate compression of the rubber. Over-compression disc-type seals (e.g. combination seals) and relatively shallow stoppers may cause the material to distort, flow into the bore, ruck at the flange, etc., and thereby cause general loss of closure efficiency. Coated stoppers, especially when the coating is harder than the basic rubber to which it is attached, generally need higher compression forces to achieve an effective seal.

Seal efficiency may change under conditions of autoclaving (e.g. steam at 115 or 121°C) and with the passage of time/conditions of storage. As a result a closure may have to be evaluated for integrity during several stages of its shelf life.

Intravenous (IV) solutions

IV solutions were originally in heavy glass containers with screw closures. Although such systems suffered from several problems (possible contamination from cooling water etc.), they are still in use in various parts of the world. The introduction of the DIN standard with a rolled- or crimped-on overseal retaining a rubber stopper improved the seal efficiency. Plastic has gradually gained in popularity as either preformed or blow fill seal moulded containers. These have been available as single port or multiport versions, which may or may not involve rubber stoppers and/or welded extensions. Due to the nature of the product and its use, closure integrity is more critical with IV solutions. However, certain packs (which are not blow moulded) are manufactured by welding or heat sealing, hence these seals also need continual evaluation. (Ports may be sealed by a number of methods.)

Since many IV packs are overwrapped (some prior to autoclaving), usually to reduce gaseous or moisture permeation factors, this may also add to the overall pack integrity and needs evaluation before and after autoclaving.

Cartridge tubes and prefilled syringes

Cartridge tubes (which may be used in a cartridge holder, disposable or non-disposable syringe unit) and prefilled syringes both have two closure systems: a plunger-type seal which acts as an internal piston to expel the product and an end seal which may be pierced, ruptured, part removed, prior to expulsion of the contents. The plunger or piston internal seal must prevent leakage and microbial ingress while maintaining ease of movement during use. There is, therefore, a conflict between the degree of interference to retain a seal and the ease of movement, partly achieved by lubrication (e.g. silicones on the rubber).

The top seal (overseal) may be a small stopper, a modification of a stopper, a disc or a combination-type system. Each normally requires rubber under compression held in position by an aluminium crimped, rolled-on, etc. overseal. The second sealing surface may be glass or plastic. In the case of glass cartridge tubes, these are invariably produced from the tubular or cane glass process, hence suffer from imperfections associated with this ‘shaping’ process. Plastic cartridges have never proved popular but are available.

Prefilled syringes can also be made from tubular glass or by moulding in plastic (e.g. polypropylene). These units may consist of either a single or double (bi) compartmental type. The latter then involve three seals, as a seal must be achieved between the two compartments. Syringes are further complicated at the end seal by the presence of a fitment for a needle (e.g. Luer) or by having a needle already moulded or fitted. These protrusions may then demand a further cover or seal, e.g. to protect the needle and prevent microbial contamination.

Prefilled syringes are usually packed into individual (sterile or sterilised) sachets, hence this provides an additional barrier to gaseous/moisture exchange and microbial ingress. However, this does not eliminate the need for closure integrity control, and this must start with quality of design. Elimination of critical defects in glass and plastic components (cartridge tubes and syringes) is increasingly being carried out by inspection systems, e.g. visual and high-frequency, high-voltage units.

Cleanliness

Although low particulates put an ever-increasing demand on sterile products, their presence at a seal or closure interface adds to leakage seepage risks. Combination seals, which were renowned for the generation of aluminium particles (usually from movement during transportation), are therefore now less used. However, some seals can create particles during the closuring operation, particularly if rubbing or tearing occurs (e.g. against relatively minor imperfections).

Conclusions

To support their high standards, sterile products require the greatest attention to detail in the quality of design stage, the highest quality standards and most effective quality assurance and quality control procedures. The fact that the seal is usually based on rubber means that the effectiveness and integrity of the total closure system has to be evaluated at several phases of the product shelf life, i.e.

1 initially
2 after autoclaving or sterilisation of components and aseptic assembly
3 during several stages of the product shelf life
4 at the end of the shelf-life period.

Appendix 11.2:
ReferencesÐsterileproducts

1 Myers, J.A., Contaminated bottles of autoclaved fluid, *Lancet,* **1389,** 24 June 1972.
2 Myers, J.A., Microbial contamination of packaged fluids after sterilisation, *Pharm. J.* 308–310, 13 April 1974.
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8 *Non Destructive Testing Handbook,* 2nd edn, Vol. 1, *Leak Testing,* USA.
9 Denyer, S. and Baird, R. *Guide to Microbiological Control in Pharmaceuticals,* Ellis Horwood, 1990.

Appendix 11.3: Aerosol seals

Aerosols differ from other packs partly because they are pressurised and partly because of the number of seals. For example, a tinplate can normally has about five seal areas.

Due to the complexities associated with the seals, most aerosols are pressure tested by passage through a water bath at 55°C. This test normally identifies the presence of serious leakage by the release of air bubbles. However, many aerosols can suffer from slow leakage which is frequently highest immediately after the filling and assembly of the can and valve system. This usually occurs because the rubber or synthetic gasket systems involved swell (thereby improving the seal) once in contact with the propellants which have solvent-type properties.

As this loss is far more serious with small aerosols (e.g. metered dose inhalation products), tests are carried out on a continuous basis to check that initial loss and subsequent steady loss (after the gaskets have swollen) are under control. This usually means that aerosols are trayed off for a period prior to final packing, i.e. labelling and cartonning, etc., and are then individually check weighed for higher losses. Sample aerosols are also kept under selected conditions with weight losses being checked over longer periods.

Where plastic packs are now used, additional weight losses may occur by permeation (through the plastic).

Appendix 11.4: Closure systems and stress cracking

As many closure systems rely on interference, impression, interlocking forces, etc. to achieve a seal, this applied stress provides potential for either physical stress cracking or environmental stress cracking. Which occurs may depend on the design of the moulding, whether any contact material (e.g. the product) acts as a stress cracking agent, or a combination of both. Examples of cracking include horizontal cracks which may follow the thread (screw caps), vertical cracks on push-on closure systems, flaps lifting from the top of the cap (frequently an extension of 'doming'), or vertical cracking in bore fitting systems. Each can usually be associated with flaws in the moulding operation, poor design or the presence of a true stress cracking agent. If the last of these is established, the choice of the wrong grade or type of plastic may lead to environmental stress cracking (ESC). This can initially be established by taking samples of plastic (in line with the Bell Telephone Test), putting in a notch or V shaped cut, and stressing them by bending in the product held at 50 or 60°C. The samples are then observed to check whether the notch extends into a crack after a relatively short testing period. Although this type of test may give an indication that the proposed material is suspect, running a parallel test with a known poor stress crack resistance grade may be useful, as this can indicate whether the formulation contains a stress cracking agent. Typical stress cracking agents are detergents, wetting agents, certain preservative systems (e.g. benzylkonium chloride and bromide) and volatile oils.

An additional test, however, is still advised on actual mouldings since processing aids (e.g. mould release agents) may add another dimension to the test. A typical test on screw caps is to apply them at a higher torque (probably double that which would normally be recommended) under the conditions of a Hedley test (pack filled or part filled with product) and then store at 60°C for 48 h (minimum period) to 2 weeks. Samples are regularly examined and the period leading to cracking recorded. If cracking does not occur with the product, but does in the presence of the standard Igepal, this normally reveals the long-term weakest point of the closure system. The removed neck test with overtight closures may be used as a QC test to check deliveries or as a test to compare different cap designs or similar designs from different manufacturers.

It should be noted that changes in mould dimensions (wear of moulds, changes in moulding conditions), even if these remain within acknowledged specifications, have to be assessed throughout the life of both closure and container mouldings. If regrind is allowed into the process, items produced from this will again have to be regularly checked.

Although environmental stress cracking was initially associated with low-density polyethylene, and one means of reducing this risk was the use of materials of a lower melt flow index (MFI), 'cracking' can occur with a range of plastics. The cause of this cracking may be associated with a strain which is in-built into the moulding or it may subsequently be created or increased by the wedding of the closure with a container finish. Tests such as those applied above may therefore indicate a weakness in the total system rather than specifically identifying the cause (e.g. if a component cracks on a circular object, i.e. a plug, 180° from the injection moulding point, cold welding work might be suspected). This, therefore, means that further work has frequently to be carried out before cause and corrective action can be identified.

In the case of a screw closure, it should be evident that a closure which has one turn or more of thread engagement will suffer less thread-to-thread stress than one of, say, turn (i.e. the same force (torque) is spread over less area with the latter, hence stress cracking could be more likely). This torque force is also conveyed to the sealing surface of the container and the contact surface of the closure, hence areas receive and convey a greater force (onto the cap). Studying how a stress occurs with the closure—container system is therefore a useful part of avoiding stress cracking problems.

Appendix 11.5: Upside-down, on-head, or on-cap stacked packs

Certain packs are designed for the container to be upside-down, i.e. sit on a wide flat cap. Typical examples are found in plastic tubes, and bottles which use wide diameter caps (i.e. shrouded caps). As the challenge to the closuring system in such instances may be greater than that found in right-way-up capped containers, leakage, or more likely seepage, tends to be more prevalent. This is because the inverted system has a product seal contact where any pressure change (dimensional or airspace, expansion/contraction) endeavours to force liquid out or air in. Some manufacturers recognise this risk by transporting upside-down packs closure upwards.

Appendix 11.6: Some references and standards

- BS 1918 Pt. 1 1984, Continuous thread finishes.
- BS 1918 Pt. 2 1981, Crown finishes.
- BS 6652 1982, Child-resistant reclosables.
- BS 3130 Pt. 3, Glass containers and closures.
- BS 3313 Pt. 1, Aluminium capping foil for glass containers.
- BS 3313 Pt. 2, Aluminium capping foil for skirted closures for plastic containers.
- BS 2006 1984, Specification for aluminium collapsible tubes.
- BS 4230 1977, Metal collapsible tubes for eye ointment.
- BS 4839, Blow moulded polyolefin containers.
- BS 5638, Blow moulded unplasticised PVC containers.
- BS 6499 1985, Specification for metal screw necks, caps and inner seals for metal containers.
- BS 5789, Specification for screw threads for plastic containers.

US methods

- Measuring torque, T3205.
- Thread application and removal torque, T3759, D3991.
- Screw cap liner compatibility, T3202.
- Screw cap MVT in lining, D3199, T3201.
- Heat seal strength, PIFA 2/74.

Pressure sensitive tapes

USA standards:

- Tensile strength, D3759.
- Unwind force, D3811.
- Peel adhesion 180°, D3330.

Holding power to:

- fibreboard, D3652
- caliper, D3652
- impact resistance, D3812
- water penetration rate, D3816.

Strapping:

- flat steel (and seals), D3853
- non metallic (and connections), D3950.

General references

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2 Driscoll, D.J., New technologies enhance trend to fewer basic types of liner, *Packaging Technol.,* April 1982.
3 Aleff, H.P., A comparison of thermoplastic with thermoset closures, *Packaging Technol,* April 1982.
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9 Evans, T.G. *Fits and Misfits of Screw Closures on Containers,* Link Industrial Design.

Appendix 11.7:
US finishes

US finishes are available through either the Glass Packaging Institute (GCMI finishes), Washington, DC, or glass manufacturers as special finishes e.g. OIG (Owens Illinois). Some of the more important finishes are as follows:

- GCMI 400 series, Shallow continuous thread (nearest UK equivalent BS 1918 R3/2).
- GCMI 405 series, As 400 but with depressed thread.
- GCMI 410 series, Medium continuous thread concealed bead finish.
- GCMI 415, Tall continuous thread concealed bead finish (UK BS 1918 R4).
- GCMI 425, Continuous thread for small diameters.
- GCMI 430, Continuous thread pour out glass finish.
- GCMI 450, CT thread finish—wide mouthed containers.
- GCMI 480, Pour out glass finish.
- GCMI 485, Combination CT and polyethylene sifter top snap cap glass finish.
- GCMI 490, Combination snap and screw cap finish.
- GCMI 500, 530, 550, 555, Threaded crown finishes.
- GCMI 600, 607, 609, etc. Crown finishes.
- GCMI/OIG 1600 series, Pilfer proof roll on.
- GCMI 2710, Biological finish.