It was recognised that ‘pester power’ influenced brand choice in store. Characters featured on-pack were both a strength and a weakness as children quickly switched character allegiance with age and peer pressure. Most parents, in any case, were becoming fatigued by characters and pointed out that many girl heroes were pink and delicate whereas boy heroes were action figures. They did not want gender issues causing squabbles amongst children.

Amongst the team, there was a feeling that the new brand would be wise to feature natural values, represented in a simple way that could span a wide age group of children rather than adopt more specific and intense characters. Parents were also keen to try and restrain children from messy eating, some making comparisons with Tetrapak-type mini-drinks, where the straw often proved to be more of a device for spraying juice than for drinking it. A small sample of the competitor products are shown in Fig. 18.8, illustrating tubes and pouches, the most radical of pack forms currently in the UK market.

Design concepts

As is common practice, the design team now began by working on unit containers, considering a wide range of pack concepts. It was felt that although research was

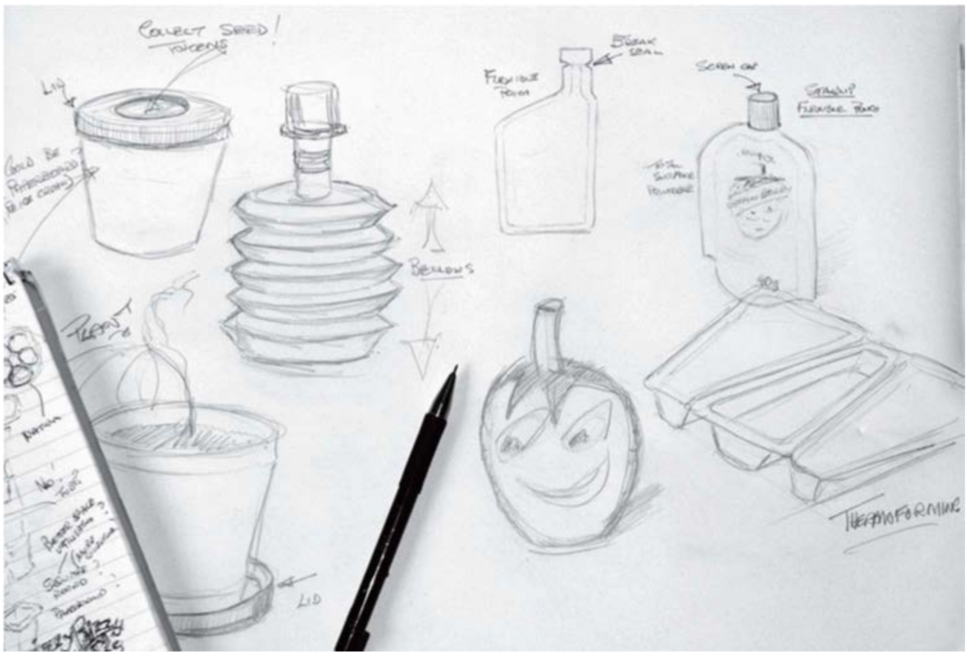
18.8 A selection of yoghurt for children already on the market, concentrating here on pouch and tube formats.

already beginning to influence some directions, the team should attempt to be open minded and receptive to all ideas and not introduce too many constraints. The concept range included pouches and tubes but also other forms of squeezable packs (Fig. 18.9). While there were advantages in the tube format, freezability, cost, novelty, and ease of collating five per pack, there were also disadvantages. Secondary packaging would have to be robust as the unit packs could not contribute to stacking strength. Also, the parental reaction indicated a resistance to purchasing this format.

As the conceptual phase continued, two major design routes were emerging. Both favoured rigid containers where yoghurt would be eaten with a spoon. Thermoformed pots were seen as more conventional but in line with brand values. In addition, the company already had experience of this format, supplying own-label yoghurts. It would also be possible to shape the 'pots' to allow five per outer carton or sleeve, meeting the one-per-day requirement of the brief.

The second route explored traditional paper-based 'pots', associated sometimes with high quality ice creams. It was felt that this format could provide a more natural and better quality image and also differentiate the product from competitors. In many ways, this is the opposite of tubes. While it was thought that it would appeal to parents, it perhaps lacks the fun (and hazards) that children might enjoy by squeezing tubes.

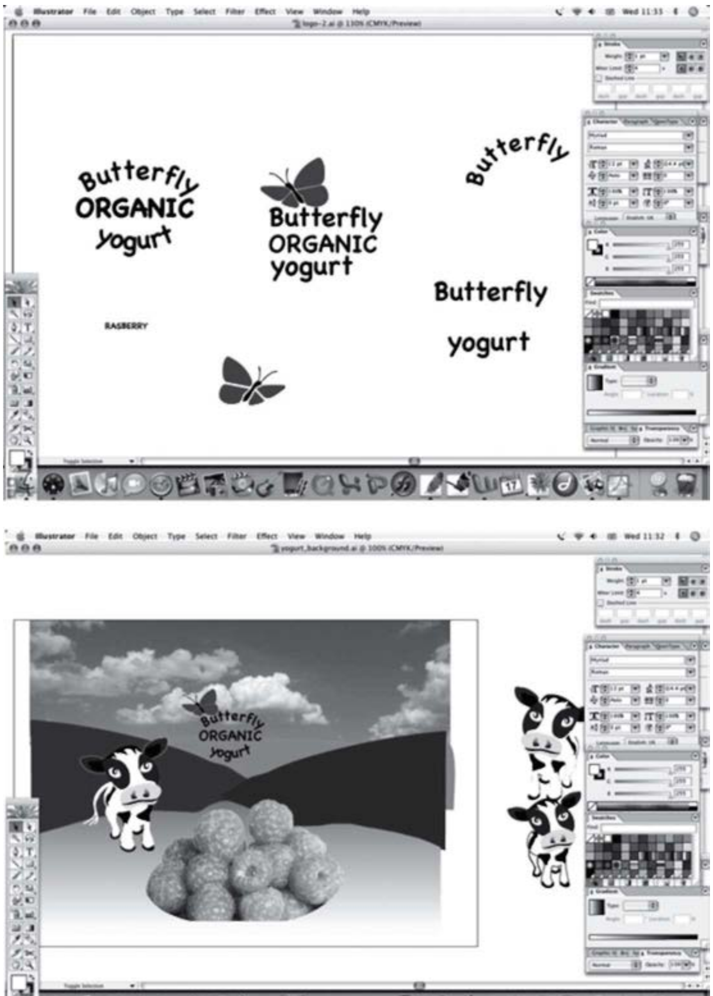
In each case, the team considered secondary uses for the packs. Thermoformed packs were considered with simple insect shapes moulded into the base. The team acknowledged that seeing an outline of an insect at the base of a yogurt pot is more fun for a child than an adult but the pack could later be reused as a mould for producing



18.9 Initial sketches of possible concepts in yoghurt packaging design.

clay or plaster casts. The paper pot could find secondary use as a small plant pot, using the wooden spoon as a label. The team could see how encouraging the link with a natural product and nature itself could be the basis of promotions. Free seeds, supplied through a web-based ‘children’s’ site in exchange for codes on the packs themselves, could form the basis of a marketing dialogue and user database.

Experimental graphics concentrated on natural elements but began to develop illustrations of animals to feature on-pack and in subsequent advertising (Fig. 18.10). Mock-ups were made of a range of design ideas, the paper pot mock-up carrying experimental graphics shown in Fig. 18.11. The paper pot, however distinctive, was difficult to collate efficiently into fives, a major disadvantage and one that would



18.10 Some rough graphic concepts for yoghurt packaging design. It is often quicker to work with sketches but, in this case, the designer chose to work directly with Adobe Illustrator.

18.11 Mock-up of paperboard yoghurt pot. The rough graphics from the previous figure were converted to an arc shape, printed and simply applied to an ice cream carton – a quick and effective way of creating a mock-up.

challenge the brief. Thermoforming, on the other hand, allowed for production efficiencies, providing web-fed forming, in-line filling, sealing and sleeving.

Design analysis

The environmental performance of packs was important per se but, in the context of a natural organic product, of significance to an environmentally aware target group. The tubs and lids could be made from rigid paperboard; these frequently have a thin plastic coating that interferes with recycling. Newer coatings are claimed to overcome the problem being both recyclable and biodegradable. At this stage there was some doubt about coating performance in contact with acidic yoghurt and a cost implication to be investigated. As mentioned earlier, the thermoformed tray concept provided efficiencies in production and in cost. The plastics were not immediately recognised as recyclable and overall appearance more difficult to market as an organic natural product.

All work was presented to the client company and design recommendations made during a formal presentation. The rationale was explained for making decisions and a programme of further work proposed. Here, unfortunately, we are forced to leave the case study at this point to maintain client confidentiality. The case study, however, provides a flavour of how the design process works in practice and, in particular, how introducing mock-ups begins to bring the project to life. The study shows that understanding consumer groups is key to developing packaging that will meet their needs and reflect their lifestyle values and behaviour. Ultimately, the commercial reality is about designing packs that help sell products.

18.5 Conclusion

Packaging design involves creative, technical and analytical disciplines and, as we have seen, follows a process that seems linear and logical but is often cyclical and occasionally tangential. Nevertheless, the design process as outlined here has been proved to work in countless design studies and with different types of organisations.

18.6 Sources of further information and advice

18.6.1 Packaging design books

The following books provide good sources of design information.

David Dabner (ed.), *Graphic Design School*, London, Thames and Hudson, 2004. Good coverage of the design process with a chapter on packaging design by Bill Stewart.

John Grant, *The New Marketing Manifesto: The 12 Rules for Building Brands in the 21st Century*, London, Texere, 2000. Another slant on how brands are established.

Adrian Shaugnessy, *How to be a Graphic Designer Without Losing your Soul*, London, Laurence King, 2005. Mainly graphic design but useful, showing how designers work.

Bill Stewart, *Packaging Design*, London, Laurence King, 2007. Complete guide to packaging design.

18.6.2 Brainstorming and creativity

There are numerous websites covering brainstorming techniques, but the following source is recommended to help stimulate creative thinking.

Alan Fletcher, *The Art of Looking Sideways*, London, Phaidon, 2001. A selection of thoughts from one of the most interesting, talented and outstanding designers of modern times.

18.6.3 Useful websites

www.monbiot.com – UK environmental activist
www.europa.eu.int – Source for European packaging legislation
www.euromonitor.com – European marketing reports
www.landor.com – Useful packaging design case studies
www.pearlfisher.com/ – Branding, structural and graphic packaging design at its best

18.7 References

www.interbrand.com/best_global_brands.aspx, Best Global Brands, 2009, accessed 12/01/2010.
www.mintel.com, Yogurt – UK – May 2009 – Companies and Products, accessed 12/01/2010.

19
Printing for packaging

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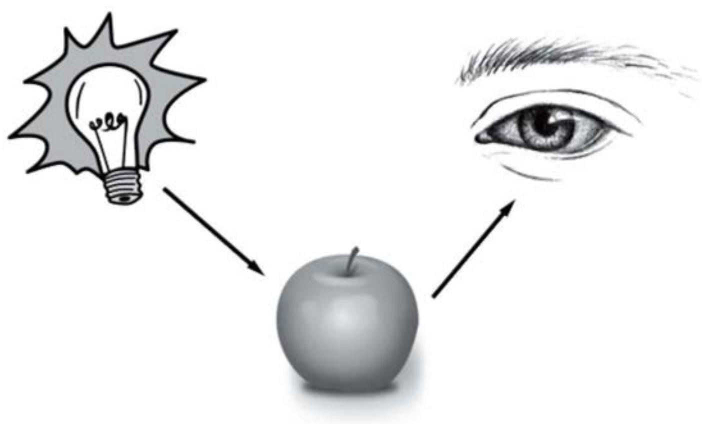
Abstract: This chapter reviews key principles and techniques in the colour printing of packaging. It discusses colour description and measurement before going on to review colour mixing and printing techniques. It also outlines key issues in graphic design, reprographics and pre-press processes, including proofing and other quality control techniques.

Key words: packaging, colour printing, reprographics, pres-press.

19.1 Introduction

Colour is one attribute used to describe the appearance of an object. In fact we use a whole host of these when we examine an object, e.g. texture, gloss, transparency or opacity. The sensation of colour is our brain's interpretation of signals received by the eye. Therefore, in order to see colour, three things are required: a light source, the object and an observer (Fig. 19.1). In most cases an object appears coloured as it is reflective; these are termed 'surface colours' although there are other types, namely self-luminous objects such as a television which creates colour by converting electrical energy into a form of light. It is surface colours that are critical in the appraisal of colour for packaging since the surface colour produced in packaging tends to be formed by a pigmented or dye-based surface coating or plastic.



19.1 Requirements for viewing colour.

19.2 Light and colour

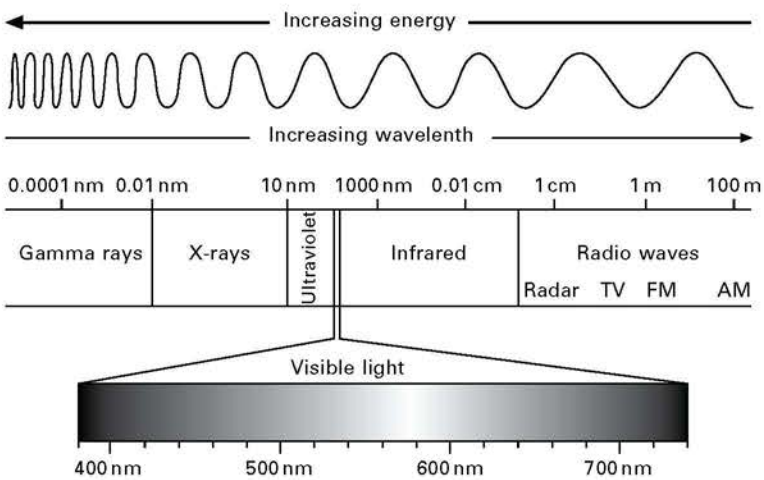
Visible light such as sunlight or white light can be described as electromagnetic radiation or waves with wavelengths ranging between 380 nm and 730 nm. Our understanding of this comes from Newton who showed that white light could be split into all of the basic colours via a prism. Figure 19.2 shows the scale of electromagnetic radiation and the visible part of spectrum with approximate wavelengths for each basic colour. It is an understanding of light and its interactions with objects that gives us an understanding of surface colours. Surface colours appear as a result of selective absorption of specific wavelengths from white light. For example, a white light shone onto a plain paper surface is reflected evenly across the spectrum to cause a balanced set of visual signals to be passed from the eye to the brain. The brain interprets this as white (Nobbs, 1998).

When white light is directed at the pigmented/dyed surface of a coating, plastic or fabric it reacts in a different way. The pigments or dyes present within the surface absorb or scatter the light so that the visual signal received by the eye is no longer balanced. When this happens certain wavelengths from the visible spectrum are now missing or reduced. This causes the brain to interpret the signal differently, i.e. coloured. This is a relatively simplistic view of the interaction between light and materials, and for a more detailed understanding of this topic, a study of reflection (matt/gloss effects), refraction (rainbows), defraction (shadow effects) and scattering (opacity) should be conducted.

19.3 The description of colour

A number of terms are used to describe colour:

- visual descriptions such as green or blue, light or dark
- emotive descriptions such as vibrant or mellow
- colourist descriptions such as dirty or clean, strong or weak.



19.2 Electromagnetic radiation spectrum (from Antonine Education, www.antonine-education.co.uk).

There is a standard set of terms which are widely used in the coloration industries. All descriptive terms fit simply into one or more of the three categories used.

19.3.1 Hue

The hue describes the colour or its family and these can be seen in the split of white light from the visible spectrum. There are six colours or hues: red, orange, yellow, green, blue and violet; the colours of the rainbow (indigo, the seventh hue is missing and in fact was added by Newton to include a seventh colour. He added this to create symmetry with the seven notes in the musical scale) (Nobbs, 2002). If one attempts to describe colour, it soon becomes apparent that there are specific hues which are more important than the others. These are known as unique hues or psychological primaries. These psychological primaries are: red and green, blue and yellow. All of the other hues can be described by a combination of these four primaries, e.g. violet can be described as a blue-red. The primaries are also separated into opponent pairs since one can never use the two opponent pairs to describe a colour, e.g. the object is never a yellow-blue or a green-red colour.

19.3.2 Lightness

We can use the term lightness to describe neutral shade objects, e.g. white, black or grey. Lightness can also be used when describing a colour by adding it to the hue for example light blue or dark blue. It is important not to confuse the term lightness with that of brightness since brightness is dependent on the viewing conditions of the object being described, e.g. the more intense the light source the brighter the colour viewed. This is a result of lightness being a relative term; as an example a mid-grey object will always look mid-grey regardless of the viewing conditions.

19.3.3 Intensity of colour

Intensity of colour is best described as the intensity of the sensation when viewing a colour. It helps us to distinguish between strong saturated colours and weak pastel shades. The term used to describe the intensity of colour is chroma. Chroma is a relative term in that it describes the intensity of sensation of an object viewed under a light source compared to white viewed under the same conditions. If the intensity of the light source is altered, the intensity of both the white and the object being viewed alter by the same amount and therefore the intensity of sensation between the two remains the same.

19.4 Colour vision

Now that we understand what is required to see colour and the basics of colour description, it is useful to understand how the eye can visually appraise hue, lightness and intensity.

19.4.1 The human eye

The structure of the human eye is shown in Fig. 19.3. The light sensitive area of the eye where an image is formed is called the retina. Light is focused onto the retina by the cornea and lens. The amount of light focused in this area is controlled by the iris; it is the aperture at the centre of the iris, the pupil that allows the light to pass into the eye depending on the viewing conditions. For example, in relatively low levels of light the iris expands the pupil to allow more light to pass into the eye, in bright conditions the pupil is smaller to restrict the passage of light into the eye. The retina itself comprises two types of photosensitive cells: rods and cones. Activity from these cells is transmitted to the brain via the optic nerve for the brain to process the information into an image or colour sensation. The rods present within the retina provide a monochromatic signal to the brain. They are adapted to provide information at low light levels (night vision). The cones provide signals to the brain at normal light levels and the information is provided in colour.

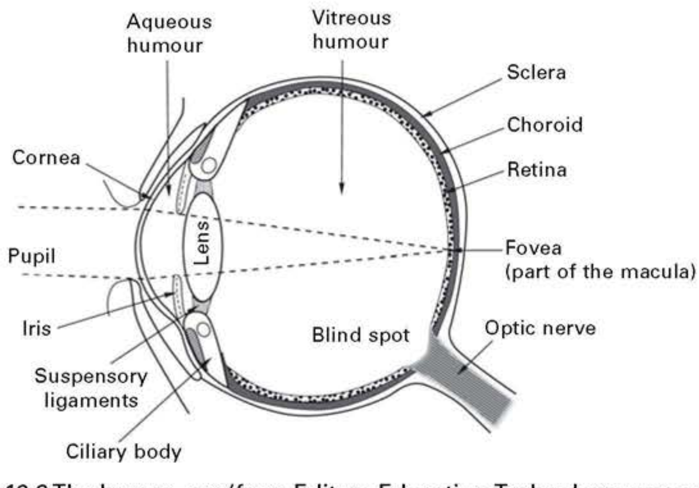
There are three types of cone cells present within the retina; each type provides information from a specific band of wavelengths from the visible spectrum. They can be characterised as follows:

- short wavelength receptors; these are sensitive to blue light
- medium wavelength receptors; these are sensitive to green light
- long wavelength receptors; these are sensitive to red light.

The intensity of signal from each type of sensor is passed to the brain which interprets the information as colour vision.

19.5 Additive and subtractive colour mixing

The function of the retina and its three wavelength specific photoreceptive cells supports the trichromatic theory developed throughout the 1800s. The theory suggests



19.3 The human eye (from Editure Education Technology, www.schools.net.au).

that the human perception of colour is a function of these three specific stimuli. This theory brought about an understanding of additive and subtractive colour mixing.

19.5.1 Additive colour mixing

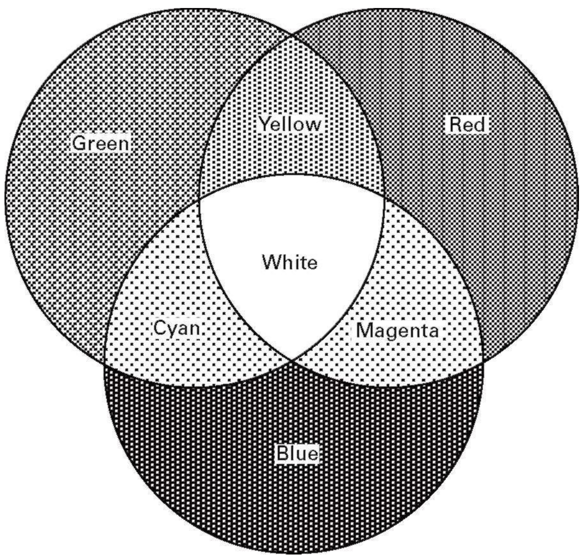
Additive colour mixing describes the creation of colour by the mixing of two or more coloured light sources. The most familiar example of colour reproduction by additive colour mixing is colour television in which all of the colours visible on screen are produced by a combination of light emitted by red, green and blue light sources (Nobbs, 2002). Figure 19.4 (and Plate I between pages 460 and 461) demonstrates the principles of additive colour mixing, which is often termed RGB from the red, green and blue colours used to form multicoloured images. It is important to note that each mix of two additive primaries forms each subtractive primary.

19.5.2 Subtractive colour mixing

This type of colour creation has already been described briefly in Section 19.2. Colours are created by selective absorption of specific wavelengths of white light. This is of huge importance when considering packaging as it is the method of image reproduction for printing techniques. The subtractive primary colours: cyan, yellow and magenta are used to control the wavelengths of light absorbed or reflected.

19.6 Other factors affecting colour

Now that we have an understanding of how we perceive colour, it is important to understand some of the things which may affect our perception of a given colour.



19.4 Additive colour mixing.

19.6.1 Illuminants

The colour of a given object is a product of the light source under which it is viewed. Different light sources have a different distribution of wavelengths of light from the visible spectrum. For example, a colour viewed in average daylight will appear different from the same colour viewed under a domestic light bulb; this is due to the domestic light bulb emitting a greater amount of light in the orange-red part of the visible spectrum compared to the more even distribution of wavelengths from average daylight.

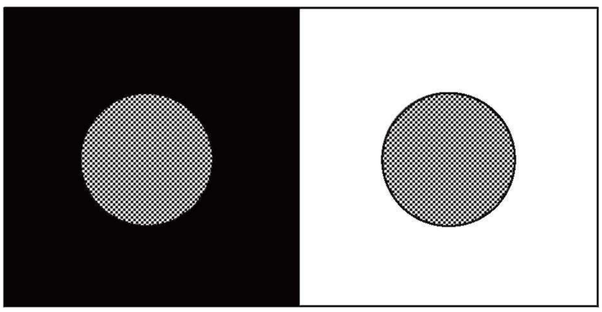
The Commission of Illuminants (CIE) established a set of standard illuminants for viewing colour. These are: standard daylight (D65), incandescent light (A) similar to a standard light bulb and fluorescent light (F) of which there are 12 different spectral distributions. The eleventh F light source TL84 is important for packaging since it is used by a number of high street stores particularly in the UK and in Europe and it has also been adopted in the Far East.

19.6.2 Simultaneous contrast

Simultaneous contrast describes the changes in perception of colours depending on the background against which they are viewed. Figure 19.5 shows two circles of the same grey with different backgrounds. It is simultaneous contrast that makes the circle surrounded by black appear lighter than the one surrounded by white.

19.6.3 Impaired colour vision

Colour blindness is caused by weak or deficient response from one of the cone cells communicating colour to the brain. It is a relatively common condition although more prevalent in men. In general it is more likely that the sufferer will confuse red and green shades since any deficiency in either long or medium responsive cones will result in this. It is possible, although rare, for colour blindness sufferers to confuse yellow and blue shades if the short responsive cones are affected. Another type of colour blindness in which all cone responses are missing results in the sufferer only being able to distinguish between light and dark from the rod response. Impaired colour vision can be tested by using Ishihara colour charts. It is important for those



19.5 Simultaneous contrast effect.

working in an environment where visual colour appraisal is a requirement to understand if their perception of colour is affected and how it is affected by a visual defect.

19.6.4 Metamerism

Metamerism describes the effect of coloured objects that match under a specific light source no longer matching when viewed under different lighting conditions. This effect is of particular importance in printing since the choice of pigments or inks used to match a specific colour can often show metameric effects.

19.6.5 Ideal conditions for appraising colour

Based on what we now know, it is clear that in order to establish a reliable assessment of colour we must observe several specific rules (Nobbs, 1998):

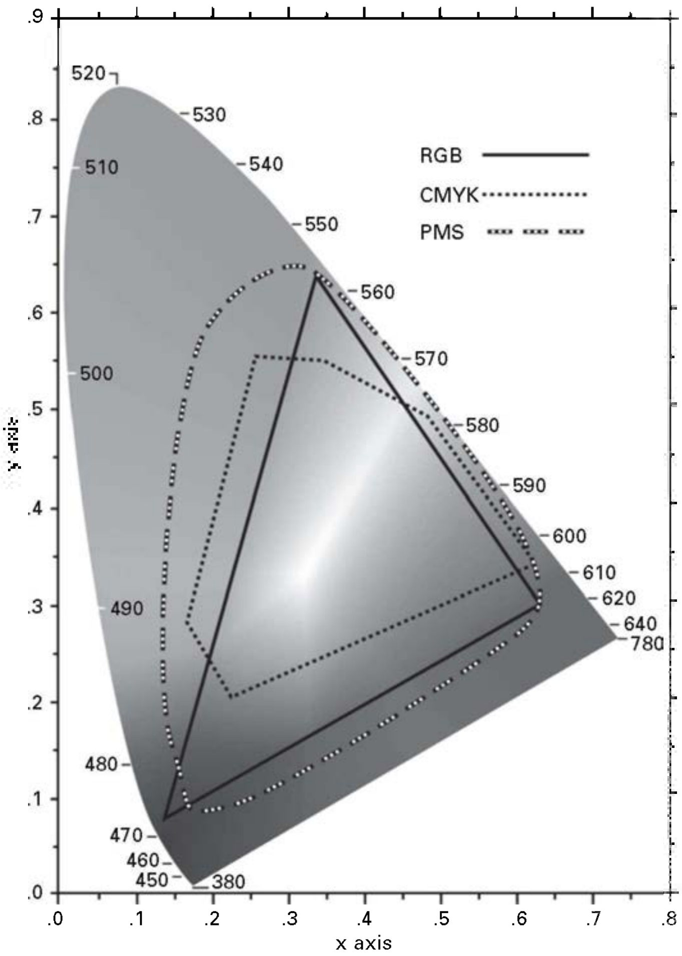
- The level of illumination must be sufficient to produce cone vision (photopic).
- The illumination must be a good simulation of one of the CIE illuminants and comparison between colours should be made under the same illuminant (if possible it should match the end use illuminant).
- The nature of the background against which the sample is viewed must be controlled. A medium bluish grey (smoky) is to be preferred.
- The field of view should be controlled so that the image produced by the lens is focused roughly on the same area of the retina.

19.7 Colour printing

In 1931, based on the theories of human colour vision, the CIE developed a diagrammatic representation of all the colours able to be perceived by the average person. The chromaticity diagram in Fig. 19.6 (and Plate II between pages 460 and 461) shows the colour gamut of our visual system. It is possible to reproduce areas of this gamut of colour by additive (RGB) colour mixing or subtractive colour mixing. The colour gamut able to be produced by subtractive colour mixing reproduction techniques compared to the gamut of the human eye is approximately shown in Fig. 19.6 (and Plate II).

19.7.1 Printing process colours: subtractive colour mixing

Colour printing makes use of this method by printing one or more of four specific inks each designed to remove specific wavelengths from white light. These are cyan, magenta, yellow and black (CMYK). When cyan, magenta or yellow are printed, the transmission of light from the surface is altered, for example when cyan is printed, wavelengths of light above 580 nm are absorbed and the transmission of light back to the eye is focused in the blue-green part of the spectrum, 400–580 nm. The same can be said of magenta and yellow absorbing light between 490–580 nm and 380–490 nm, resulting in transmission of light from the blue-red and green-red parts of the spectrum, respectively.



19.6 Chromaticity diagram (including approximate RGB, CMYK and PMS colour gamuts).

Each of these specifically designed inks is transparent so that combinations of two or more of these colours can absorb light through layers of one another. In an ideal case, a printed layer of all of these colours should absorb wavelengths across the whole of the visible spectrum and produce black. In practice, the black produced by a combination of CMY tends to be weak in sensation and results in a heavy coating weight made up of three colours which can be easily replaced by a single ink film of one. It is for this reason when printing process colours that a Black is used. The letter K denoting black refers to its use as the 'key colour.' It should be noted that black does not always have to be the key colour but is in most cases.

19.7.2 Tonal reproduction and halftone printing

Certain printing methods have only the ability to produce consistent thickness of ink. Tonal reproduction is achieved by printing in halftone. Halftone is created by printing dots of specific size in different areas. This was first demonstrated as a monotone or single colour reproduction and can be seen everyday in the black and white image reproduction of newspapers or this book. The effect is due to limitations in the resolution of the eye. By printing dots close together the eye blends them to give the impression of grey tones. Applying this same principle to the four process colours resulting in a mosaic of dots of each colour overprinting one another, it is possible to create a full colour image. The XY chromaticity diagram in Fig. 19.6 shows the plot of colour sensations the average human can perceive. Reproduction of colour using CMYK or subtractive colour mixing can achieve a gamut of colour within this plot. This is approximated in Fig. 19.6.

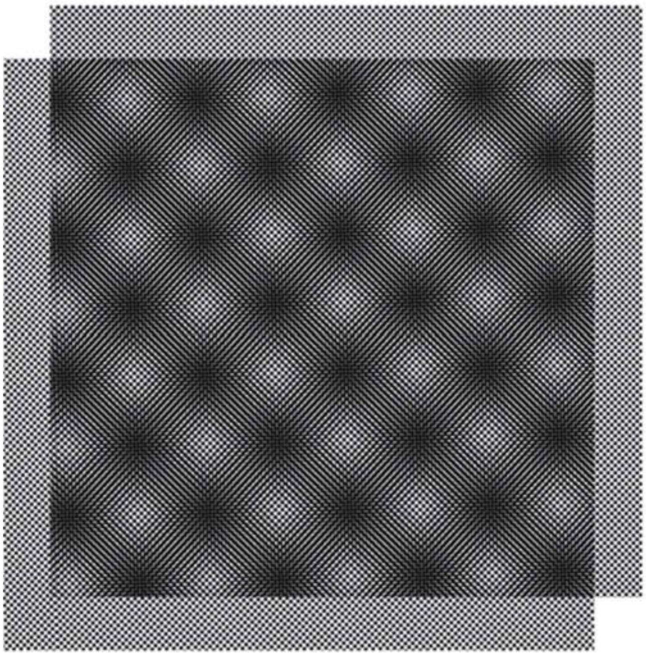
Screening and resolution

The image resolution for halftones is determined by the screen ruling. The term screen ruling is used to describe the frequency of dots in a given area of image. For conventional screening (amplitude modulated screening or AM), the halftone dots are arranged in a grid structure termed the screen. The quality of the halftone cell is determined by the overall cell size (lines per inch, lpi) and the dots (dots per inch, dpi) required to create the cell. The screen ruling (lpi) is the number of dpi used to produce the halftone image and the resolutions used will determine the screen rulings that can be produced. Course screen rulings tend to be used in low quality reproductions, e.g. newspapers, and fine screen rulings for high quality reproductions, e.g. fashion magazines or art prints (Kinyo, 2004).

Screen angles

The screen angle refers to the angle formed by the direction of the screen ruling in relation to the vertical finished position of the image (Kinyo, 2004). The role of screen angles is particularly important for multicolour image creation since each colour (CMYK) is required to have a different angle. Assigning the wrong angles to each colour can result in a compromised image appearance. If the wrong angles are applied to colours the image tends to produce objectional interference patterns (moiré) or screen clash. A moiré pattern can be seen in Fig. 19.7. Moiré patterns are produced when two similarly repetitive patterns are almost but not quite superimposed (Kipphan, 2001). Assigning the same angle to all colours can also be a cause of colour variation since each dot should print in the same position but any misalignment may result in variable transmission of light.

Typically in process printing the angles are assigned so that each colour is separated by an angle of 30°. Cyan, magenta and black are assigned angles furthest away (30° separation) from each other and yellow is assigned an angle 15° from the other colours. Yellow is assigned the 15° difference as it is less likely to visibly clash with the other colours. As a general rule, printing colours in halftone over or into other halftone colours should be assigned angles as far from each other as possible without being on the same axis. Difficulties can arise for complex artworks with four or more colours printing in halftone into or over each other, as there may



19.7 Moiré pattern (from Kipphan, 2001).

Dot shapes

Dots may be printed in a number of shapes, for example: round dot, square dot, elliptical dot and diamond dot. It has been reported that the elliptical dot gives smoother midtone (30–70% dots) particularly for lithographic techniques (DTP Tutorials, 2008). The effect of dot shape on print is a complicated one in that the choice of dot shape is influenced by the image to be printed. Elliptical dots may give a smoother transition to a vignette throughout the midtones; however, it is likely to be more susceptible to moiré patterns. Square dots tend to print sharper in the midtones but they too are more susceptible to moiré patterns. The round dot is least susceptible to moiré but more likely to show dot gain. The round dot tends to be the most common in packaging printing; however, for the screen printing technique it is the least favoured choice (Coudray, 2007). It is difficult to establish the ideal dot shape because applications and process techniques are often too diverse (Kipphan, 2001).

19.7.3 Hexachrome

The limitations in the colour gamut able to be produced using CMYK can be demonstrated by comparison of the Pantone swatch guide for special colours to process reproductions (Pantone solid to process guide or Color Bridge guide). The original Pantone guide produced in 1963 was introduced as a colour matching system (Pantone matching system, PMS) for use with special inks blended from 14 individual colours printed in solid and various tints. Its use as a colour matching tool is now widespread and has been adopted by most suppliers, converters and buyers of packaging.

Following soon after the original Pantone guide for special/spot colours was the colour bridge or solid to process guide which shows the closest match achievable for CMYK to the original special colour. When compared visually to special colour swatches achieved through mixing special inks to provide unique colours, the process reproductions appear noticeably less vibrant or do not match at all. Only around 30% of the Pantone spot colour library can be accurately reproduced using process colours. In 1994 Pantone introduced a six-colour system which addresses the limitations of the CMYK colour gamut in part. In addition to cleaner CMYK inks, orange and green (in some cases a strong blue shade of ink has been used to replace the orange or green) were added to complement the modified process set and to maximise simulating the original Pantone spot colour library (Reid, 2008).

In Fig. 19.6 the improvement of printable colours based on the Pantone system compared to the standard CMYK is approximated. In fact between 50% and 90% of the original Pantone library can be achieved using hexachrome. One potential issue with the use of hexachrome is that the increased brightness of the inks required to achieve the improved gamut can result in a loss of lightfastness properties. This increase in gamut is advantageous since it allows improved colour reproduction from an identical set of inks. This allows the printer to produce a range of work without costly wash-ups and the opportunity to produce composite reproductions of more than one item at the same time (Davey, 1999).

Hexachrome initially had limited success since it was not embraced by the industry in general; this may have been due to the cost of implementation, a lack of understanding of the print processes by design and marketing personnel, or the failure of pre-press systems to provide adequate conversion software. However, hexachrome popularity has steadily grown, particularly in certain areas of the packaging market and for specific production processes. Hexachrome does have its limitations, namely:

- its colour gamut still cannot reproduce many Pantone matching system (PMS) special colours
- colour control can be problematic in specific production situations requiring tight control of pre-press and production machinery, e.g. variations in dot gain from one printing press to another may result in unacceptable colour variation of the product
- the lightfastness of the finished product may be compromised
- existing colours/artworks/standards may be compromised or re-established when reproduced in hexachrome.

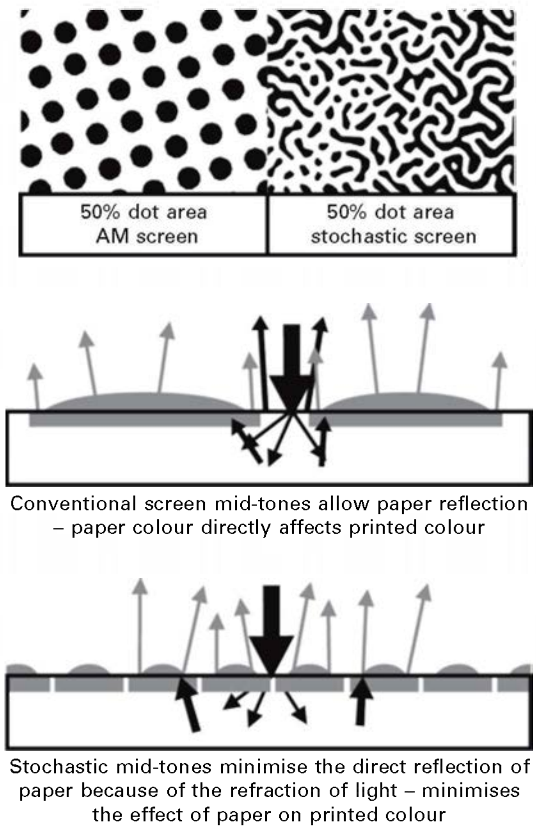
19.7.4 Alternative screening techniques

The use of conventional screening described in Section 19.7.3 could cause a problem when using hexachrome since the number of angles available is limited and may result in moiré patterns emerging in certain designs. The use of alternative screening types overcomes this potential issue and is used in other situations to impart specific advantages.

Stochastic screening (frequency modulated or FM)

Unlike conventional screening (AM) which alters the size of the dot in specific areas in an ordered pattern to create tonal variation in an image, stochastic screening puts dots of equal size, distributed randomly in varied volume to create the tonal variation in an image. Clearly the first advantage of this type of screening is the elimination of interference patterns (moiré) since the dots are randomly distributed without angle. Stochastic screening can also give the visual benefit of cleaner colour reproduction in certain tonal areas. This is a result of the reduced paper effect, since stochastic screens cover a greater percentage of the substrate than the conventional equivalent as shown in Fig. 19.8. It follows from this that ink usage can be reduced for the printer.

Stochastic screening also allows greater control of printed colour since variations in ink film weight on press result in a reduced colour change due to reduced tonal value increase (TVI) effects (see pp. 458–459). Another benefit of using stochastic screening is its ability to hide a certain amount of misregistration between colours. If colours in conventional screening are misregistered, the effect is more noticeable as a result of the ordered distribution of dots. The random patterns of stochastic screening



19.8 Reduced paper effect (from Braden Sutphin Ink Co., 2009).

disguise this to some extent which can lead to reduced wastage for the printer and a greater registration tolerance on press. The advantages of stochastic screening are clear: its use should be well controlled on the press and selected for the appropriate reproductions for the benefits to be realised. Its use is, however, not universal and the process may not prove beneficial for flesh tones, pastels, low contrast subjects, rough paper types or average process colour illustrations (Prince, 2009).

Hybrid screening

Hybrid screening is designed to make the most of both conventional and stochastic screening types, combining the advantages of both across the full tonal range, e.g. using AM screening in flat tints and flesh tones, whilst shifting to FM screening for fine detail or moiré sensitive areas. Many companies have developed variations of stochastic screening and hybrid screening each marketed to sell the benefits in the final printed result. Hybrid screening is commonly used in flexographic printing to disguise its inability to reproduce fine screens in comparison to lithography. In this case the hybrid will result in FM screening of some type in the 0–10% dot regions and the 90+% dot regions.

19.7.5 Special colours

The use of special or spot colours in printing is common; in general their use is to add something extra to the reproduction of an image or artwork. As already described, the reproduction of colour using CMYK or hexachrome does not provide a full colour gamut and reproduction of certain colours using these colour mixing techniques can be poor. In these cases spot colours can be introduced to overcome this problem.

Spot colours

A spot or special colour can be described as a single or blend of one of 14 (or more) base colours created from individual pigments. In the western world the most common method of description of these colours is the PMS guide created by Pantone Inc. (there are other guides, e.g. DIC, TOYO). The PMS guide shows the recipe and resulting colour swatch for combinations of the 14 basic colours. The results of these blends are cleaner and more vibrant than the CMYK representation. It is for this reason that special colours are often used for communicating important brand logos or corporate colours. Special colours are also often used in 1–3 colour designs as this may be more cost effective than using process colours. Typically these spot colours can be used in conjunction with process colours to add visual impact and in some cases can be used to replace one or more of the process colours to reduce the total number of colours.

The use of special colours can also be advantageous for a higher quality result not only as a result of the improved perception of colour. Consider the control of colour on a printing press; it is usually simpler for the printer to control a single ink film throughout a production run than to control all four process colours potentially reducing the likelihood of colour variation. Also in terms of registration of fine positive or negative type (e.g. instructions or ingredients listings) the reproduction in a single ink tends to be clearer than a combination of two of more colours which may exhibit some misregistration.

Special effects

Special effects can be relatively simple and designed into packaging. For example, the contrast between matt and gloss effect varnishes in specific areas can be striking. Special effect inks or inks containing special effect pigments can be categorised by the type of effect they impart to the final product. The use of special effect pigments has grown steadily in recent times, particularly in the packaging industry primarily to give products an exclusive edge.

Metallic effects

These inks, originally used in the automotive industry, impart a metallic lustre to the finished product. An ink is prepared with metallic pigments (generally aluminium or bronze flakes) within it. The metallic pigments act as tiny mirrors resulting in a bright metallic quality to the coating depending on the angle of viewing (Gilchrist, 2001). Standard metallic ink formulations can be viewed in the current PMS colour guide and an extended metallic PMS guide shows other shades that are available. In recent years the introduction of high lustre substrates, e.g. vacuum metallised films and paperboards, has further improved the quality of lustre achievable. A good example of the potential of metallic ink effects has been demonstrated by the Metal FX® technology (Metal FX® Technology Ltd, 2009). Although this is not a new technology, it demonstrates the principles of printing transparent inks (CMYK and other special colours) over a high lustre metallic ink to create metallic effect images.

Fluorescent effects

A series of fluorescing inks can also be printed which in daylight give rise to colours which possess a remarkable vivid brilliance as a result of the extra glow of fluorescent light (Christie, 1993). The pigments used in fluorescent inks tend to be used for their brilliance properties. However, they do have a drawback in that they tend to exhibit reduced lightfastness due to their dye-based composition. This can be a significant problem, particularly for packaging which may require high levels of lightfastness when on display.

Pearlescent effects

The original pearlescent inks/coatings which are still commonly used are based on mica flake pigments, typically coated with a thin layer of an inorganic oxide. These pigments reflect and partly transmit incident light leading to multiple reflections of light from the layered material. Interference between the reflected light beams results in specific colours at particular angles (Gilchrist, 2001). A commercial example of this type is Iriodin® by Merck. Improvements in this type of pigment technology have led to new improved inks which can exhibit more dramatic colour changes (often termed colour shift inks). Commercial examples of this type are: Colorstream® & Miraval® by Merck, Chromaflair® by Flex Products and Variochrome® from BASF. It should be noted that for the most dramatic effects close attention should be paid to the colour of the coating beneath the application of pearlescent pigmentation since the effect can be compromised considerably. To make the best use of pearlescent pigments, they should be applied over dark colours so that maximum incident light is absorbed allowing the pigment reflection to be the dominant response.

Other special effects

It is not only visual effects that can be printed to add value to a pack or product. In terms of our senses, colour is only one of many that we perceive when we examine an object. Table 19.1 describes other special effects used in the packaging industry.

19.8 Graphic design, reprographics and pre-press

In Section 19.7 the basics of image formation through printing were discussed in terms of tonal reproduction by subtractive colour mixing with process colours, screen ruling/angles and screening/dot types. The following section describes the processes of artwork or graphic design and the preparations for printing including modern platemaking techniques.

19.8.1 Graphic design

The discipline of graphic design is used in a wide range of industries for communication of information, an idea or concept. In the modern printing industry we can think

Table 19.1 Other sensory special effects used in packaging

Sense	Description
Touch	Tactile varnish effect used to engage the sense of touch, e.g. velvet type feel
	Braille applied to packaging for communication purposes to the blind
	Scratch off revealing hidden information beneath an opaque layer, e.g. lottery cards, contraceptive pill calendar
Smell	Encapsulated smells applied to a product which release the odour either by scratching or breaking a seal
Hearing	Smart packaging which can convey a message via sound, e.g. musical birthday card messages, prescription drug reminders or communications for the blind

of graphic design as construction of an artwork from a given brief. This may be something relatively simple such as the layout of text in a monotone printed book (the origin of graphic design, typesetting in the earliest reproductions of printed text) or more difficult graphic communications such as the setting of a magazine with multiple images or a packaging product required to meet legislative guidelines and promote a particular brand.

Artwork design

The graphic design industry is now dominated by computer-aided design or desktop publishing. The current types of software for graphic design are capable of performing most tasks the designer may wish to carry out enabling start to finish artwork creation, including image, type, solid colour and halftone or vignette manipulation. The computer-based nature enables the designer to immediately view the artwork on screen and the effect of alterations made to it. It is vital that graphic designers have at least a basic knowledge of print and the reproducible aesthetics of printing technologies so that designs can be readily reproduced with minimal additional work, making the most of the printing method intended to be used.

Computer-aided design (CAD), computer-aided manufacture (CAM)

CAD is typically used in the packaging industry to design the shape and style of a pack. The design of packaging construction is often used as a unique selling tool within the packaging industry. However, the use of CAD is not only a selling tool for novel packaging designs but is also used to create layouts/repeats for packaging manufacturers ensuring minimal waste. An example of CAM in the packaging industry would be the suitability and performance assessment of a specific design/ layout/repeat manufactured on a small scale (e.g. plotting table) before large-scale manufacture.

19.8.2 Reprographics and pre-press

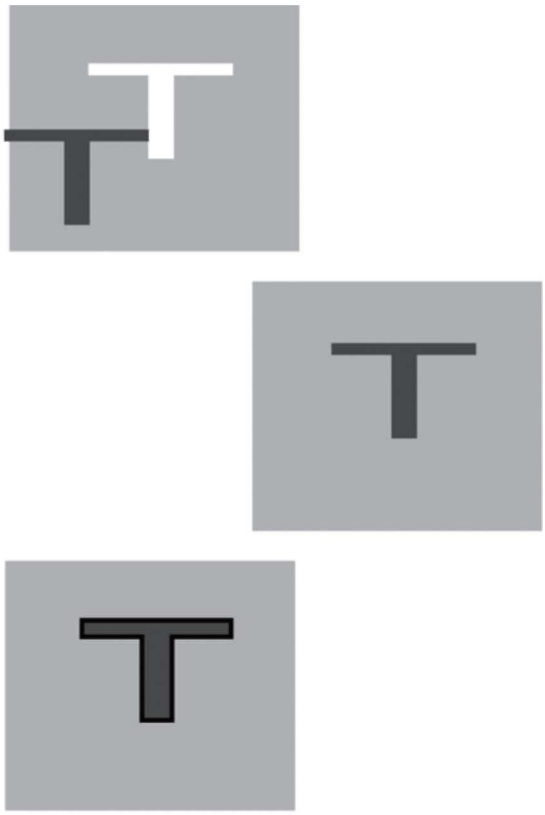
The term reprographics (repro) essentially refers to the reproduction of graphics in some form or another and pre-press refers to the work required for an artwork to be printable including platemaking. In terms of packaging printing this means the conversion of the graphic design artwork file to a file that is able to be reproduced by the chosen printing method. Each printing method has different requirements based on its individual properties and limitations. It is vital for the reprographics operations to be run in close communication with the print production, since the final product is highly dependent on not only the design itself but the way it has been set to print. The processes of graphic design and reprographics tend to be sold as a service to packaging manufacturers where in-house capabilities are not available and to packaging buyers seeking consistency across multiple items of a particular brand. The following sections show examples of typical repro operations.

Colour separations

Colour separation involves the creation of individual printed channels or separations from an artwork file and assigning the relevant parts of the artwork to print in the relevant areas in each chosen colour. In terms of artwork conversion, separation into process colours is now done at the click of a button using an artwork design or specific reprographics software. However, it is not always advisable to simply separate artworks into four-colour process or hexachrome images since the complexity of the resultant separations may be difficult to print. The introduction of special colours or additional colour separations is carried out at this stage and can reduce the printing difficulty and/or improve the overall printed effect.

Trapping (choking, spreading, gripping)

The trapping of two or more colours refers to the overprint (or underprint) at the interface between the two (or more) colours in the artwork. It is common to apply a degree of trapping taking into account the particular printing process to avoid gaps or remove overlap which may occur with misregistration on the printing press. Figure 19.9 shows a typical example of grip applied to two colours to prevent gaps



19.9 Trapping of two colours.

showing at an interface between two printing colours. The solid colour applied first has a letter 'T' in reversed out text and the overprinting colour is a slightly larger positive 'T' image. This results in the 'T' having a visibly darker border appearance around it where the two colours overlap. A negative grip could be used i.e. printing a smaller positive type 'T' into the reversed out text resulting in the substrate being visible between the two printing colours. This is often used to increase the clarity of text on some substrates that are difficult to print on such as metallised materials and plastics. Different printing processes require specific trapping rules to be applied.

The term 'kiss fit' is given to an interface when no trapping has been applied. In this situation, the reversed out 'T' and positive type 'T' would be identical in size. This prevents the border of either substrate (negative grip) or overprint (positive grip) from being visible around the text. However, this may be difficult to register in production printing resulting in an aesthetically unpleasing effect.

Dot control

The control of printed dots is also a reprographics function as much as it is a function of print production. The transfer of ink from plate to substrate will result in a tonal value increase (TVI) or more commonly termed dot gain. Essentially this is the increase in percentage dot printed when compared to the percentage dot on the printing plate/repro artwork file. Each printed colour will exhibit individual properties in terms of printed dot and this increase varies depending on the percentage dot printed. We can split printed dots into three specific regions: highlights (low dot percentages, around 20%), midtones (around 50% tonal values) and shadows (high dot percentage, around 80%) (Nobbs, 2002). The extent of TVI is often measured for a particular printing press during a fingerprint exercise in which a full range of percentage dots (CMYK and/or special colours) are printed under production conditions and analysed to give an understanding of the dot growth that can be expected during production.

TVI can have a profound effect on the final printed product particularly if the design is reliant on full colour images and/or vignettes. For example, if the magenta separation is exhibiting a higher TVI than expected during printing, the image will appear to be redder than expected. This effect should be controlled at the reprographics or platemaking stages by applying compensation to the file based on the expected performance of a given printing press. Control of this phenomenon through reprographics has far-reaching implications particularly for consistency of final product produced on different machines, using different print processes and different materials. ISO 12647-2:2004 (Graphic Technology – Process control for the production of half-tone colour separations, proof and production prints) is a standard for offset lithography used to describe process parameters for printing and the results that should be achieved to ensure conformance (Jones, 2009).

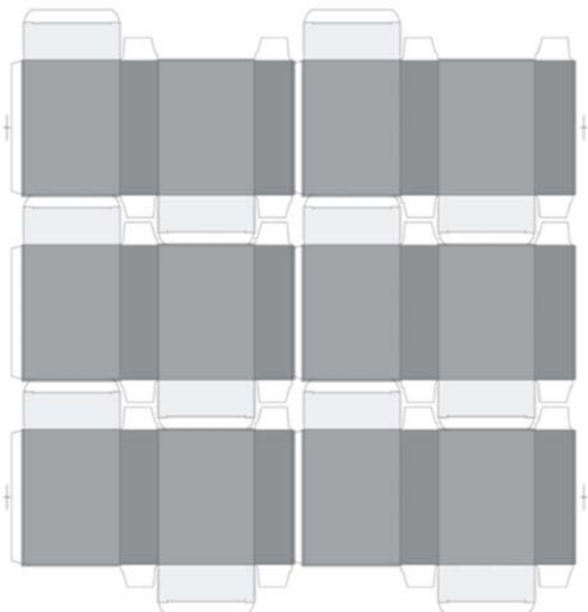
By working to this standard often requiring reprographic alteration to artwork images, it is possible to recreate process coloured images and communicate the requirements to recreate colour images consistently. A disadvantage of this type of artwork control is that it does not fully take into account variable substrates which can have a significant effect, and it is designed only for process printed images, not spot colours. Since spot colours react differently on press it is common now to carry out and provide dynamic TVI results prior to printing. This allows repro to compensate for the variable dot gain effect of special colour in formulations. Reprographics also provide the screen ruling, screening type (AM, FM or hybrid) and the dot shape for a printable artwork all of which are specific to the design and print process being used.

Step and repeat

The process of step and repeat is again built into reprographics software and is vital for the packaging manufacturer producing many thousands of items. Individual artworks are stepped onto a production layout (sheet or web repeat) so that many units can be reproduced in a singe printed impression. The step and repeat function allows the single artwork/repro file to be duplicated into set positions on a layout file (Fig. 19.10). This layout file tends to be provided by the packaging manufacturer to fit the characteristics of the packaging machinery (e.g. repeat length, sheet size) and of the artwork itself, to avoid print defects. Some reprographics programs can take the individual layout and artwork files and construct an onscreen three-dimensional image to view.

Other useful additions

At the reprographics stage for artwork conversion, it is common for the repro operators and/or print providers to add useful print production aids. For example, it is common



19.10 Step and repeat 6-up including artwork.

to add station numbers (providing traceability between positions on a given layout or repeat), company logo (confirmation of print provider), colour step wedges (used for monitoring TVI on special colours) and registration marks (to aid the printer in achieving registration quickly and consistently).

For some packaging applications, the use of deformation software may also be used at the reprographics stage and designed into the artwork. Take, for example, the shrink sleeve commonly used around plastic bottles. During the application of the sleeve to the bottle it is passed through a heating unit which causes the label/sleeve to shrink and conform to the size and shape of the bottle (Gates, 2002). At the reprographics stage the artwork is distorted to allow for shrinkage based on the bottle shape and expected shrinkage of the substrate. This results in the desired appearance of the artwork around the bottle after processing.

19.8.3 Image transfer

Once a file is ready for print, with the exception of digital non-impact printing techniques, an image carrier, usually a plate, must be manufactured. Each printing process uses different methods of image transfer and thus has a different technique for plate manufacture. Until the relatively recent digital revolution, platemaking was a labour intensive process. The development of CTP processes has improved image quality, speed of processing (thus reducing press downtime), flexibility for fast amendments and reduction in platemaking costs.

Once an artwork is ready for a digital platemaking process, the data/file is passed to a RIP (raster image processor) which transforms the various aspects of the file (text, screening, colour separations) into a format that the following plate production process can interpret. This file is then sent directly to the plate production output device. The plate production method for some of these devices is described in the following sections.

Computer to screen

The transfer technologies for screen printing are described in Section 19.10.3. Computer to screen technology works in the following way. Initially a full coverage layer of emulsion coating is applied to the screen (usually by inkjet printing) to block its mesh. Following this the image is printed, again usually by inkjet onto the relevant areas of the screen. Then the screen is exposed to an active light source and the unprinted areas of the screen are cured. The areas coated with the second printed image remain unexposed and the emulsion layer is then washed out with water leaving the mesh in the image area open and able to transfer ink.

Computer to gravure cylinder

The gravure printing process is an intaglio process (Section 19.10.3) and the image is transferred from an engraved cylinder. The image areas of the gravure cylinder are mostly mechanically engraved using a stylus and the engraving process is controlled digitally. Direct laser engraving of gravure cylinders is also available, although it is less common.

Computer to relief plate

The relief printing processes of letterpress and flexography are described in Section 19.10.3. Although traditionally letterpress plates were metal and though they are still hard in comparison to flexographic plates, they are both now commonly manufactured from photopolymer materials. So called 'conventional' relief plate manufacture requires exposure through a digitally produced film from the artwork file. Digital relief platemaking removes the requirement for this film by having an ablation layer (black heat sensitive coating) applied to the surface of the photopolymer. A digitally controlled laser removes this layer in the image areas of the plate and the plate is then subjected to UV radiation to cure the exposed areas of the photopolymer material. The uncured photopolymer is removed, commonly using solvent wash although water wash and abrasion removal systems can be used, leaving raised image areas. The plate is usually finished with drying and a UV post exposure.

Computer to off-set lithographic plate

There are a number of different processes for digital production of lithographic printing plates, although the process by which they are imaged is similar. The basic process is one of digital exposure to a light or heat source. The plate itself is coated with a material reactive to the imaging head (laser, light/heat source) and the plate is developed and non-image areas are removed. The plate may be baked to increase its life on press although non-bake technology is now common and the plate is usually coated with a water-based gum or coating to protect the non-image areas from oxidation, which could result in them accepting/transferring ink on press.

19.9 Proofing options and approval processes

Proofing is a method of checking aspects of the artwork before going to press via single or small-scale reproduction of an artwork. Proofing can be used to provide a range of checks from relatively simple checks on copy and position to full colour reproduction simulation of the likely results from the print production process. When considering the legislative requirements and brand communication implications of packaging, proofing is an important part of the artwork conversion process. Examples of different proofing options and their uses are demonstrated in the following sections.

19.9.1 Digital proofing

Digital reproduction of an artwork is now a common tool used to assess artworks for the required qualities. The methods of digital proofing vary with each system in terms of the printing method and the properties the software capabilities can provide. The printing methods are the non-impact methods inkjet printing and electrophotography printing (see pp. 476–478). Relatively simple assessments of artwork can quickly be made by reproduction on desktop/low quality digital printers in terms of copy, content and aesthetic impact, although the colour reproduced is not accurate nor the dot structure used in most printing methods. The reproduction of artwork onto transparent film is also commonly used as a copy check tool to lay over an existing/ altered file and even a production printed sample or product.

Application specific high quality inkjet or eletrophotographic proof printers are now common. The inclusion of software that can handle printing press profiles to build in production TVI and PMS colour control (including special colours) mean that digital proofing is now a popular method of assessment of artwork. The ease of production and low cost compared to traditional wet proofing methods mean that it has gained much popularity. Development of digital print proofing and its accuracy in terms of reproduction matching that of specific processes and machines is ongoing. Digital proofing is likely to be the dominant proofing assessment method of the future.

19.9.2 Wet proofing

Wet proofing is the traditional method of pre-approving an artwork and is used as a matching tool for a packaging converter to work with. Essentially wet proofing is a small-scale version of the printing process being used for full-scale manufacture. Wet proofing is available for all of the major print processes (lithography, flexography, gravure, screen). The advantage is that the actual components used in full-scale reproduction can be used to make the proof (substrate, inks, varnishes and plates) giving an accurate representation of what is achievable. It is popular with printers since the reproduction exactly replicates the dot structure and any variation from the proof on press can be spotted more easily. However, this proofing system relies on the proofing operator to match the supplied properties of the production press as any deviation from this will result in a difference between the printed product and the proof.

19.9.3 Sign-off and approval

If a proof has been made accurately (to the specific properties of the actual printing press) with either wet proof or digital proofing technology, then we can be confident that the actual printed product will be an exact or close representation of the proof supplied. This is particularly the case for wet proofs if relevant TVI information and actual production material have been supplied and adhered to. Given the importance of brand communication, it is not uncommon for representatives of the brand to attend a press approval or press pass at which sign off is achieved by approval of the actual printed package during production. If the requirements are not met, it also allows the opportunity for fine tuning artwork/colours to match expectations. In some instances the brand owners may prefer to proof their artwork on the production printing press although this is rare as it is a high cost option. Most packaging manufacturers will have procedures set in place for approval processes from the very first stage through to product manufacture and these should include common customer requirements relevant to their product.

19.10 Technological aspects of printing processes

The major print processes can be characterised in many ways; each process has a unique mechanism with advantages/disadvantages associated to its use. All print processes are essentially a method of communication via image transfer. Characterisation of these processes may be by their market dominance or common features such as ink type, drying method and press format. The processes in the following sections are described according to their mechanism of image transfer; however, other general characteristics and properties are illustrated first.

19.10.1 Ink types and drying

In any printing process, it is the purpose of the ink to impart the information by producing an image on a substrate. The desired properties of inks are as follows:

- They must be controllable during the application by the printing process both on the press and on contact with the substrate.
- They must dry or 'set' at a rate commensurate with high speed printing.
- They must convey the information as a thin film or halftone dots.
- They must be suited to a large range of substrates including paper, board, plastics, ceramics and metals (Thompson, 1998).

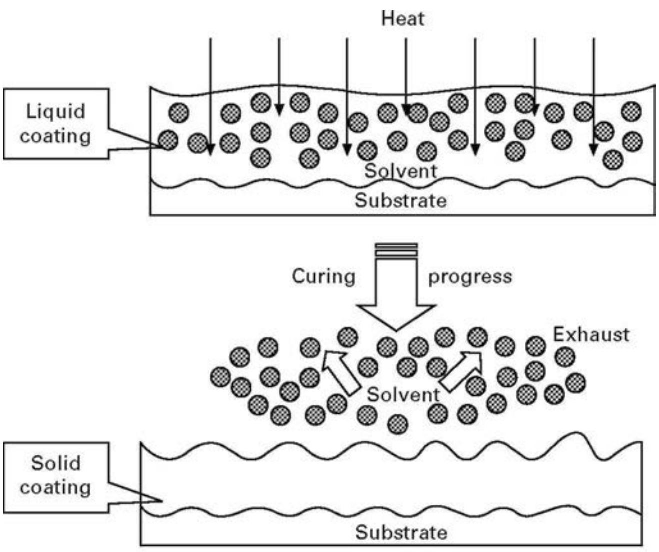
A traditional definition of an ink is a combination of pigment/dye, binder precursor and/or film former and/or curable monomer and solvent, assembled in such a way as to produce a near homogeneous composition (Guthrie and Lin, 1994). Inks are formulated with the requirements of the printing process in mind and they can be classified in terms of their application. Table 19.2 shows the general properties of inks designed for each print process (Leach and Pierce, 1988).

Two other useful classifications of inks are the nature of the ink formulation and mechanism of drying which can be dealt with simultaneously. The two dominant ink types by formulation are examined here and their methods of drying described. Firstly, there are so-called 'conventional' solvent-based inks in which the pigment, film forming and additive elements are carried by the solvent as a usable ink. The solvents tend to be organic solvents, such as petroleum distillates, alcohols, oils and resins or water in water-based formulations; they are an important component since they directly affect the properties of the ink in printing and the final film formed. The method of drying for these types of inks is by evaporation of the solvent from the ink film, although absorption and oxidation effects contribute also. This method of drying is shown in Fig. 19.11.

Secondly, in relatively recent times the printing industry has embraced ultraviolet (UV) drying technology. Although these inks are more costly and have certain health and safety implications, such as handling and product taint from residual monomers/photoinitiators, they are widely used throughout the industry. The main

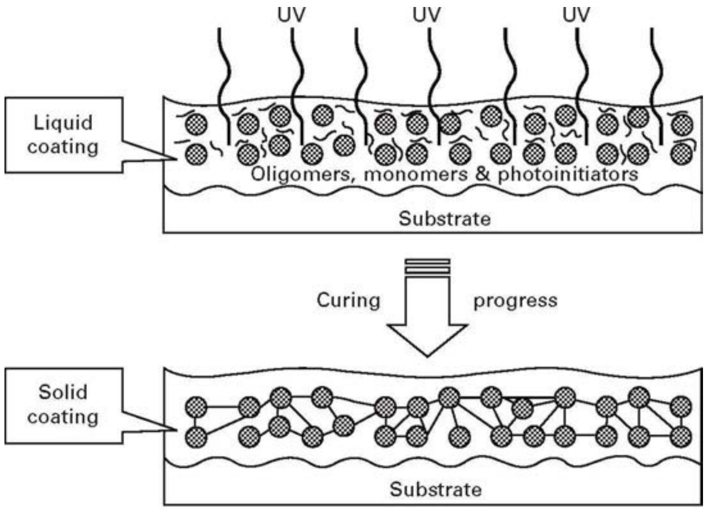
Table 19.2 Properties of inks for various printing processes

Printing inks			
Printing process	Pigment (%)	Viscosity (Pa s)	Ink film thickness (μm)
Letterpress	20–30	50–150 (relatively high viscosity or paste inks)	0.5–1.5
Lithography	20–30	40–100 (relatively high viscosity or paste inks)	0.5–1.5
Gravure	10–30	0.05–0.2 (relatively low viscosity or liquid inks)	5–8
Flexography	10–40	0.05–0.5 (relatively low viscosity or liquid inks)	0.08–2.5
Screen	Highly variable	Dependent on film thickness and fineness of mesh	Up to 12
Ink-jet	1–5	0.05–20 (mPa s) (relatively low viscosity or liquid inks)	<0.05

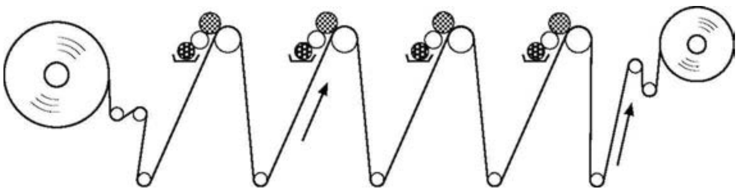


19.11 **Conventional drying mechanism.**

advantages of these types of inks are that they dry extremely rapidly on exposure to UV radiation, undergo no drying prior to and during printing, and they release no volatile organic compounds (VOCs) into the atmosphere since they do not contain conventional solvents. The inks contain photoactive species which when irradiated with UV radiation initiate a polymerisation chain reaction. Figure 19.12 shows the basic mechanism of drying in which 100% of the printed ink is converted into the solid film. Other methods of drying such as electron beam curing or infrared drying are used in the printing industry and in the case of infrared can be used in conjunction with conventional/evaporative drying and UV curing.



19.12 UV cure mechanism.



19.13 In-line printing configurations.

19.10.2 Printing press configurations

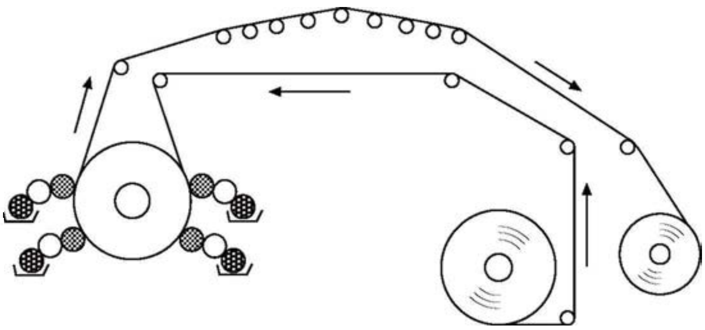
In general we can say that printing presses are designed in one of three formats. Each basic design is described in this section.

In-line presses

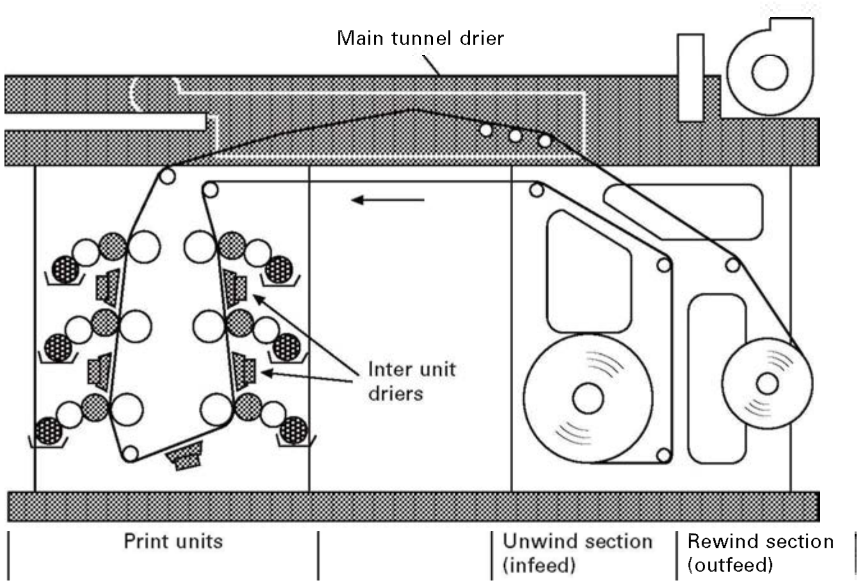
The configuration of this type of design is as expected, with each print unit following the next in a line. Figure 19.13 shows a typical example of this type of press design. The in-line press can run either sheeted material or reels. It is a popular set-up in the packaging market. These types of presses can be set up to print either side of the substrates, often termed 'perfecting'.

Central impression (CI) presses

A printing press with a design of this type has each unit distributed around one central impression cylinder as shown in Fig. 19.14. These types of presses tend to be web-fed. The advantages of CI presses are that they take up considerably less floor space than in-line presses and can hold tight registration as a result of the support from the



19.14 Central impression (CI) printing configuration.



19.15 Stack printing configuration.

central cylinder, which can be of particular advantage when working with deformable substrates such as low density polyethylene (LDPE). However, they can be more expensive as a result of engineering the critical and large single impression cylinder. Also this type of configuration cannot print either side of the web simultaneously.

Stack presses

In stack press configurations the printing units are stacked on top of one another which reduces the floor space required. The space saving advantage permits more colour stations to be built in and, since the press can 'perfect', allows multi-colour printing on both sides of the substrates. A typical example of the stack configuration is shown in Fig. 19.15. Stack presses are reel fed and generally used for multi-colour double-sided work such as newsprint, magazine and catalogue work. In packaging they are popular configurations for flexible film conversion.

19.10.3 Image transfer mechanisms

In this section each of the major print processes is explained in terms of the method of image transfer. In addition, their general applications, advantages/disadvantages and recent developments are also discussed.

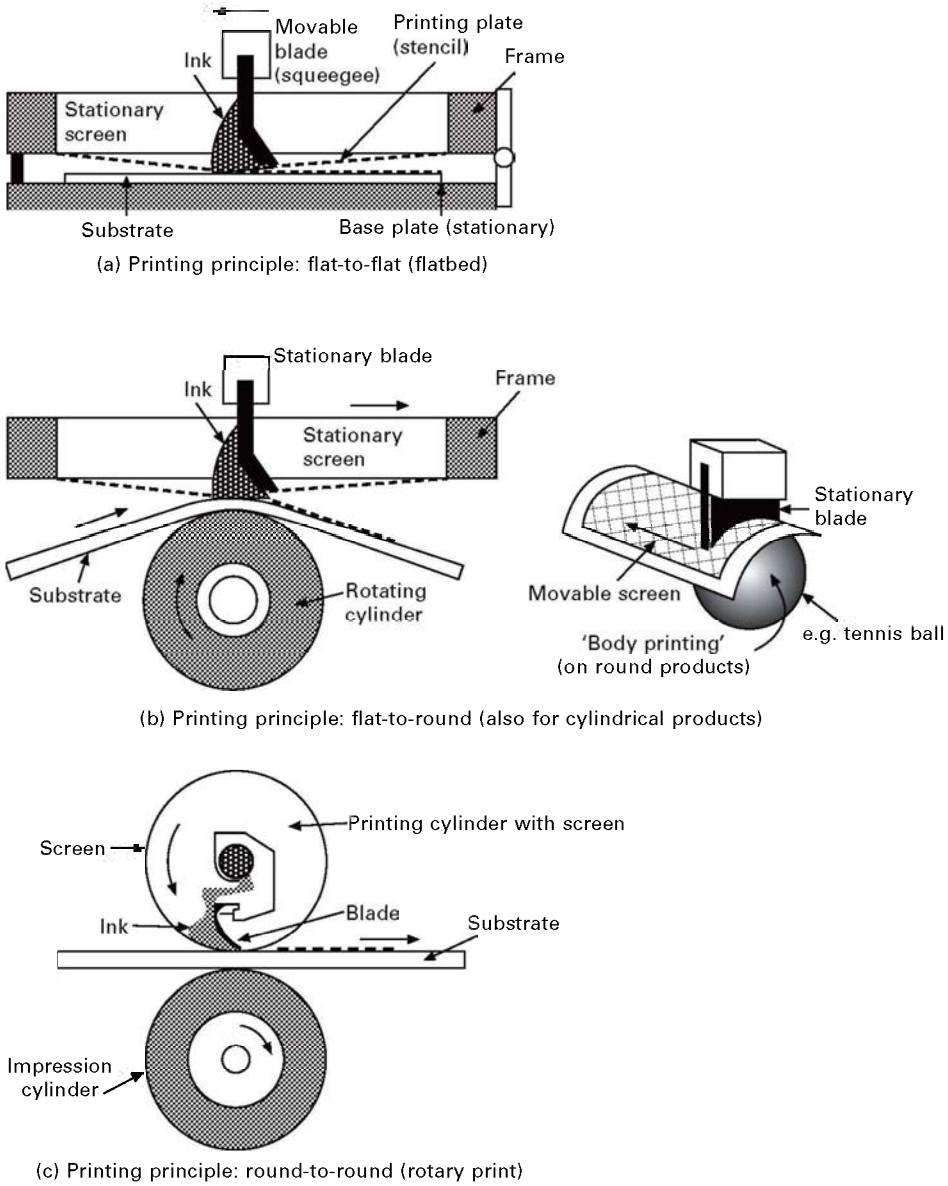
Screen printing

Screen printing is a type of stencil printing and a hugely versatile technique. It is used across a wide range of industries for image transfer due to the fact that it can print on a range of different substrates. It is used selectively for both small and large production orders. In this process, ink is transferred to the substrate through a stencil supported by a fine fabric mesh of silk (hence the term silk screen), synthetic fibres or metal threads, stretched tightly across a frame (Takai, 1999). The image areas of this screen or mesh are left open whilst the non-image areas of the screen are masked off, resulting in ink transfer through the open image areas onto the substrate (Peyskens, 1989).

Screen printing is carried out using either a flat-bed or a rotary system depending on the application. Flat-bed assemblies allow not only the printing of flat substrates such as paper or fabrics, but also of conical objects such as plastic bottles, ceramic mugs, etc. This process is known as the body printing method screen process, shown in Fig. 19.16. The rotary screen method also shown in Fig. 19.16 is generally used for longer print run jobs, typically for labels, wallpapers and textiles. It greatly improves the output efficiency for such products compared to the flat-bed method. The flat-bed method forces ink through the image areas of the screen by a moving squeegee. The screen and substrate remain stationary. The rotary screen method uses a rotating cylinder to pass the substrate into impression with the moveable screen. The squeegee remains stationary throughout.

Screen printing tends to be carried out with conventional drying inks, although UV is not uncommon. The ink film thicknesses screen printing can provide (Table 19.2) require more drying than other printing processes, often slowing the process and/or requiring a separate drying stage which adds costs to ink, energy and time. However, the large film weights have advantages, particularly for special effects such as glittering, metallic lustre, achievable opacity and tactile finishes. Also, good opacity can be obtained and this is especially useful when printing light colours on dark backgrounds, for example.

The biggest asset of screen printing is its ability to print on a wide range of substrates of all shapes and sizes; in fact it can be used to print on almost any item. Examples of screen printed items include: compact disk and DVD images, toys, traffic signs, display panels, electronic circuitry, textiles, textile transfers, ceramics, glass and wallpapers. In terms of packaging, screen printed items tend to be bottles, tubes, aerosols, labels and the large-scale advertisement posters and shelf-ready assemblies seen in shops. The speed of production, which may be considered slow when compared to other print processes, makes it less attractive/cost effective to use in certain areas of the packaging sector particularly for volume reproductions of low



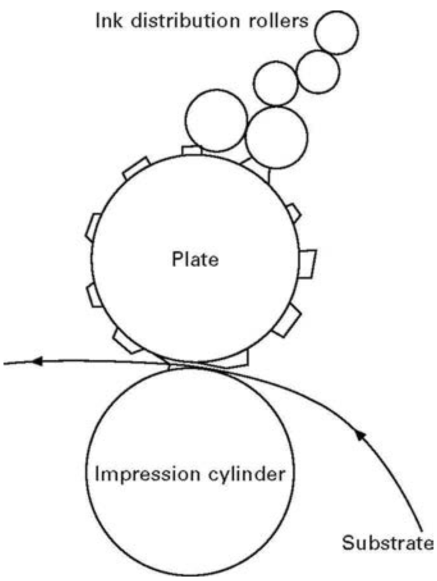
19.16 Flat-bed and rotary screen printing (from Kipphan, 2001).

margin products. In recent years the focus for development in screen printing has been on improvements in the manufacture of the screen itself, namely the development of digital platemaking (see Section 19.8.3). Image quality has also been a focus since the achievable quality compared to other print processes is of relatively low resolution.

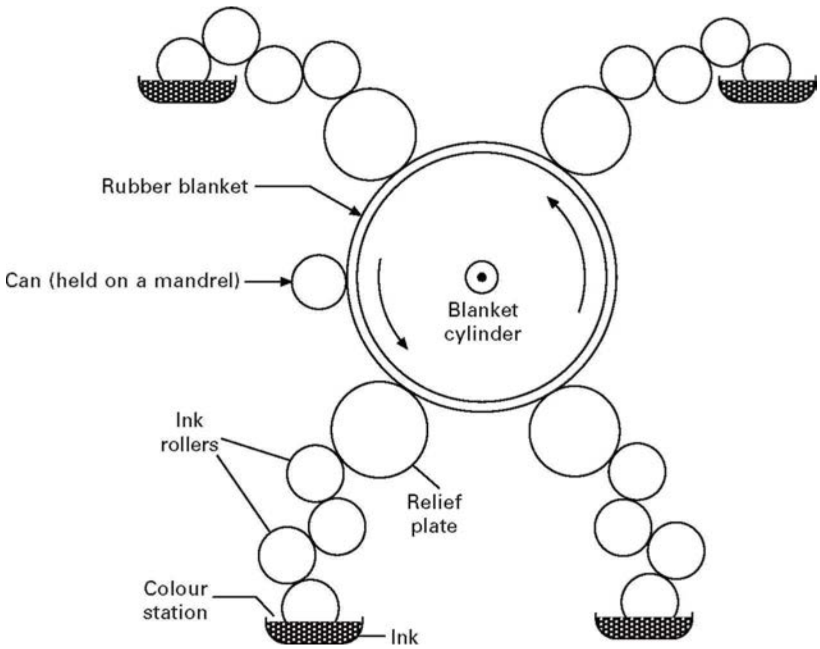
Letterpress

Letterpress printing is the oldest print process and is termed a relief printing process. The term relief refers to the fact that the printing is done by means of raised printing elements (image area). Originally the raised images would be set as a rigid solid plate made from metal (alloys of lead or tin) on a flat-bed press. These plates are now commonly made from a photopolymer material. Rotary press assemblies dominate the letterpress market. Letterpress printing requires the use of relatively high pressure, typically between 5 and 15 MPa which must be held uniformly across the relief plates on the substrate. The inks used for printing by the letterpress process are termed 'paste inks', due to their viscous nature. The inks are metered onto the hard plate by a series of metering rollers (Leach and Pierce, 1988). The plate then transfers the ink onto the substrate by impression as shown in Fig. 19.17.

In recent times the letterpress process has lost much of its market to lithography and flexography (based on the letterpress process). In general, it is now used for relatively low quality print such as newspapers, books, directories, and speciality products such as business cards and invitations. However, it is still widely used for some packaging applications particularly for label and self-adhesive label production (Kipphan, 2001), and, most commonly, for printing 3-dimensional objects such as tubes, cans and tubs, where it is known as *dry offset letterpress*. Here, instead of laying the colours down on the substrate sequentially, the image is assembled on a blanket and then transferred in total to the container (Fig. 19.18). Ink coating weights are low (compared with screen printing, for example) and line speeds are high.



19.17 Letterpress printing.



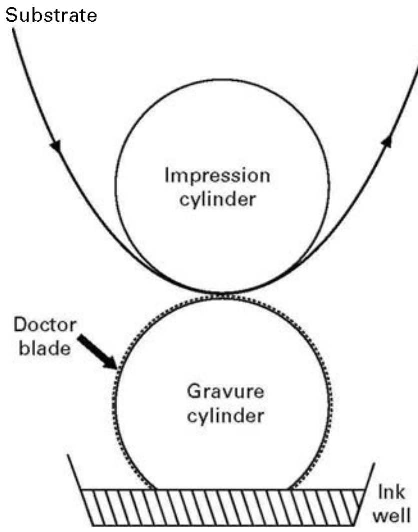
19.18 Dry offset letterpress.

Gravure

It is the simplicity of gravure printing that makes it a practical and favourable process to use. The gravure process is an intaglio process, with the image areas recessed below the non-image areas. This image carrier is known as the 'gravure cylinder'. The image is applied to the metal cylinder by means of an etching or engraving process. This image engraved/etched cylinder is flooded with ink and the excess ink is removed from the non-printing elements of the cylinder by means of a doctor blade assembly. The ink within the cells that form the image is transferred to the substrate via impression as shown in Fig. 19.19 (Leach and Pierce, 1988).

It is the gravure printing cylinder that imparts the qualities, advantages and disadvantages to the process. The high cost of these cylinders tends to promote large volume print with infrequent design changes such as wallpapers, wrapping papers, high quality magazine work as well as some areas of the packaging market. It is not cost effective for short run work. The process is capable of producing high quality image work, with lpi values of 150 as standard and higher values for high quality reproductions. This is a result of developments in the etching/engraving process allowing better tonal control through close control of cell structure and depth.

Gravure printing inks tend to be conventionally dried and are in general solvent based. The drying process is usually by hot air knife which essentially directs a stream of heated air at the printed substrate; conventional oven type drying systems are also used, as are UV curable systems. Typically, gravure printing presses are web fed (although there are some applications for sheet-fed gravure systems) and are



19.19 Gravure printing.

capable of printing on to film, metal foils, papers and board substrates. The versatility in substrates combined with high print quality and consistently reproducible results over long runs are the main advantages for gravure. It is for these reasons it is a popular process in packaging since it is very cost effective. Typical examples of gravure print in the packaging market are: plastic bags, film over-wraps, foils, labels, flexible packaging for food products, tear tapes, cartons and wrapping papers.

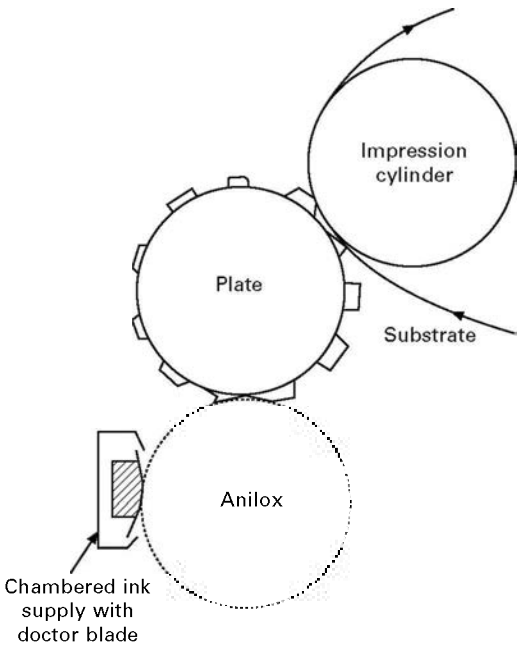
As shown in Table 19.2, the ink film thickness for gravure print is high; although this can cause drying problems, it also gives the advantages of vibrant special effects, particularly of high lustre metallic/bronzing and glitter or pearlescent varnishes. Much of the development in gravure in recent times has been concentrated on improving its costs and efficiency. Although the efficiency for high volume is high, it has lost popularity through not being able to compete for shorter run work. Cylinder engraving companies have worked on reducing the cost, time and effort required to produce cylinders (see Section 19.8.3). The main development for machine manufacturers has been the so-called 'wrap tooling' which replaces the traditional cylinder with an engraved thin plate or sleeve for quicker changeovers. Machine manufacturers and printers have also developed more elaborate press specifications allowing multi-colour printing on both sides of a substrate simultaneously and the addition of value adding/finishing processes in-line. Machine design has led manufacturers to build hybrid printing presses which incorporate units of different print process (i.e. flexography) into gravure presses and vice versa. These units can even be interchangeable depending on the printer's requirements. The result is that the benefits of the gravure process can be achieved whilst taking advantage of other process benefits.

Tampo printing has some similarities with gravure, but it is an indirect process. The design is cut/etched into a nylon, steel or photopolymer plate. The plate is inked, and the excess ink wiped off, leaving ink in the design of the image in the recessed areas. A flexible silicone pad then picks up the image from the inked plate and transfers it to the object to be printed. Dependent on its design and shape, this pad can transfer images to compound curved surfaces, smooth or rough, convex or concave, which is a key advantage of Tampo over other printing methods.

Flexography

Flexographic printing (commonly termed flexo) is a process derived from the letterpress process that was described above; it is a relief process. The main differences are the use of a flexible printing plate as the image carrier, the method of application of ink to the plate and the ink itself. In the flexographic printing process the ink is metered onto the surface of the plate by an engraved/etched roller of chrome or ceramic similar to a gravure cylinder but with a uniform distribution of cells (size, shape and depth). This roller is called an 'anilox'. The specification of the anilox determines the volume of ink transferred to the printing plate. The ink is taken into these cells and the excess ink is subsequently removed by a doctor blade assembly. The plate transfers the ink film from the anilox to the substrate by impression. This process is shown in Fig. 19.20.

The flexible printing plate, originally made from rubber, is now commonly made from photopolymeric materials. On early presses with rubber plates and no sophisticated duct control, quality was restricted to line and type work on corrugated board containers, envelopes, bread wrappers and sacks. However, with anilox metered ink feed and photopolymer plates, flexography has become a major process for flexible packaging giving high productivity and quality on filmic substrates. Doctor bladed



19.20 Flexography.

aniloxes with selected cylinder cell line counts (screen ruling) and cell volumes have raised the print quality beyond all earlier expectations (Gray, 2001). Typical lpi for flexography is now 133 lines although use of lpi values of 150 and higher have been demonstrated.

Flexography is now not only the dominant process for labelling, it is competing with gravure in the flexible market and also with other processes in the leaflets and cartons markets in packaging. Flexographic inks/drying tend to be similar to the gravure process for flexible packaging and are hot air dried solvent-based formulations. Water-based inks have gained in popularity and are widely used in specific markets such as corrugated carton board, plastic sacks and bags. The main advantages water-based formulations have are the improved environmental properties when compared to their solvent-based counterparts through reduction of VOC emissions and the health and safety impact on press operators. Water-based formulations can also be said to be more easily cleaned down and more stable on press due to low evaporation rates. However, the lower evaporation rate of water-based formulations can also be problematic particularly for non-absorbent substrates; also the use of water as solvent can result in reduced wetting of specific substrates. UV inks are also popular in the packaging market, particularly for flexibles, labels and cartons.

The flexographic plate is mounted onto the print cylinder, although it is now common to mount onto a sleeve which sits over the printing cylinder reducing set-up times. This has clear advantages over gravure printing since the cost of plate is much reduced. The most recent developments have been the introduction of digital photopolymer plates (see Section 19.8.3) and continuous sleeve systems. These advantages have won favour against the more established gravure process, particularly in the flexible market, as the plate cost is lower than the gravure cylinder allowing shorter runs and frequent design changes.

The anilox is the control method for ink application onto the plate and substrate. It is the cell volume and geometry that control the final ink film thickness on the substrate. The film thicknesses available in flexography can be advantageous for special effects as with gravure; however, the uniform distribution of cells can cause problems when printing solid colours from the same plate/anilox as halftone screens. As a result, the solid and screen work are often split at the repro stage, and printed using different plates, although plate and screening technologies are slowly removing the need for this (Galton, 2009).

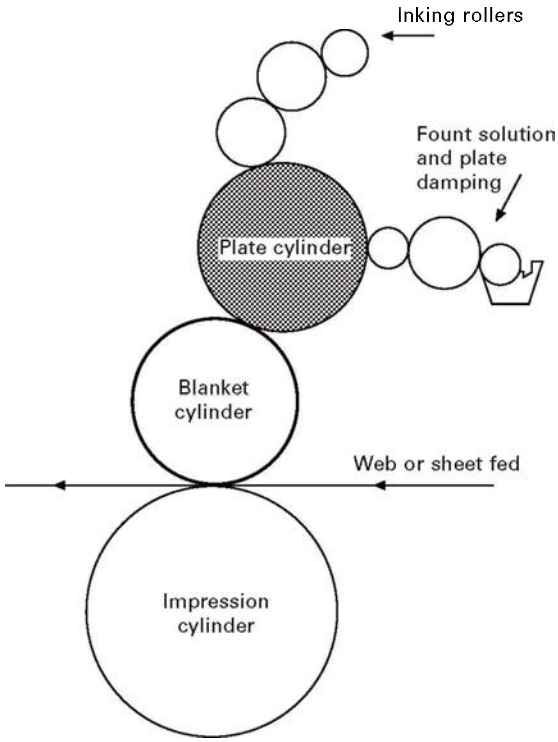
As a general rule, the screen ruling of the anilox should be higher than that of the plate to avoid interference patterns or screen clash. The developments in gravure cylinder manufacture also apply to anilox production and have contributed greatly to the quality of flexography. Sleeved anilox rolls can be also used, reducing the set-up/changeover times further. Chambered ink application and reverse angled doctor blades have made a positive contribution to the control of ink in the flexographic process. Machine manufacturers have also developed gearless printing units allowing infinitely variable printing repeats, again reducing set-up times and costs for expensive machine gears. Flexographic units are now used in conjunction with gravure units in hybrid presses and are also common as coating units for application of varnishes on sheet-fed lithographic presses.

Lithography (off-set)

Lithography (litho) is unlike other printing processes in that it is planographic. By this it is meant that the image areas of the plate are neither raised nor recessed from the non-image areas, and are separated by the mutual repulsion between oil and water. Lithographic printing is currently the most popular of the printing processes worldwide. The success of lithography is largely due to its versatility in different markets and the achievable print quality which is high; typically 150 lpi is used although it is common for up to 200 lpi to be used in art reproductions and high quality magazine work. The term offset refers to the fact that ink is not transferred directly from the plate to the substrate but is offset onto an intermediate carrier or 'blanket', which then transfers the image onto the substrate. Lithography can be web-fed for longer run work such as newspapers, forms and magazines; or sheet-fed for shorter run length magazines, books and cartons and labels in the packaging sector.

The lithographic plate (almost exclusively computer to plate, see Section 19.8.3) has image areas that are oleophilic/hydrophobic (ink accepting/water repelling) and non-image areas which are hydrophilic/oleophobic (water accepting/ink repelling). This is a result of the surface chemistry designed into the plate. The non-image areas are covered with a dampening solution, which is essentially water with additives to lower its surface tension and thus aid more complete wetting of the non-image areas of the printing plate. Ink is then applied to the image areas of the plate via a series of distribution rollers, to ensure consistent film thickness. The areas of greatest application of ink onto these rollers are controlled by the operator and ink is then transferred to the blanket. The mutual repulsion between ink and water keeps the non-image areas free from ink allowing the ink to transfer only from the image areas of the plate. The relationship between the ink and the dampening or fount solution is a complex one. If the surface tension of the dampening solution is not sufficiently low, inadequate wetting of the plate may occur resulting in transfer of ink from non-image areas. Similarly if the surface tension of the dampening solution is too low then emulsification of the ink can occur. The ink is transferred from the printing plate onto the blanket and finally transferred by impression from the blanket to the substrate. A diagrammatic representation of this process is shown in Fig. 19.21.

The ink film thicknesses of lithographic printing are relatively low (Table 19.2) when compared to those of gravure, flexography and screen printing, limiting its success for printing special effects which rely on large film weights. However, the viscosity of lithographic inks (paste inks) allows for a high pigment loading which means the colour strength can be considered good for colour reproduction and hiding power on most substrates. The ink drying mechanisms for lithography tend to be either conventional solvent-based or UV curable. For web-fed applications drying time can be built into the process to allow for conventional drying inks to fully cure before the following processes. However, in sheet-fed applications the use of spray powder assemblies is common. A fine powder is sprayed onto the sheets as they are delivered into a stack. The powder effectively acts as a spacer between the sheets allowing air to oxidise the wet ink film and prevent the sheets from blocking (sticking together) in the stack. UV curable inks have gained huge popularity in the



19.21 Lithography.

lithographic format due to the versatility within a multi-colour press, efficiency and improvement in the printing environment without the need for spray powder.

In terms of technology of printing presses, lithography has led the way such that lithographic printing presses are the most technologically advanced in many ways. Machine manufacturers have concentrated on improving the quality of the printed product achievable, the set-up times and the workflow/control technology. Advancements have been such that a good proportion of the processes required for changing from one job to another are fully automated (plate changes, size setting blanket and roller washes). Repeat job data can be stored on press or delivered to press from pre-press to improve set-up times. Colour can now be measured using spectrophotometry on printed colour control strips and automatic adjustments made in real time. This technology lends itself to sheet-fed lithography; although it is certainly used in the other processes, it is not generally an automatic feature of the presses. Machine configurations have also become more advanced with hybrid presses containing flexographic coating stations added particularly for overvarnishing. In fact the most recent additions to lithographic machinery have been cold foil blocking units and thin plate rotary cutting units.

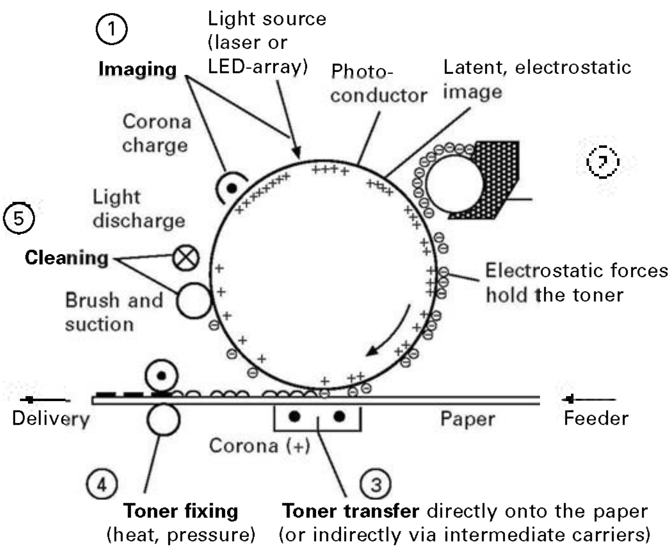
Waterless lithography (dry offset) is another relatively recent technology which negates the use of a dampening solution. The technology is built into the printing plates. The non-image area of the plate has an oleophobic coating to repel the ink to replace the need for the dampening solution applied in standard offset. Its popularity has been limited due to the increased cost of the plates and their susceptibility to wear. Also the inks used can create problems since each ink is uniquely temperature dependent, requiring the press operator to closely control the printing temperature for each unit.

The other major development in the chemistry of lithography is the removal of alcohol (isopropanol, IPA) from the fount solution. IPA has been used in the fount solutions as an additive for the water, to reduce the surface tension and achieve better wetting of the plate. However, it is expensive and a VOC, therefore its removal has cost and environmental benefits. Fount chemistry is such now that IPA can be removed; in fact it is banned in some areas. Its removal can result in more vibrant colour reproductions since it acts as a solvent to inks used and removes colour. Also, it requires tight control of all aspects of the press to be successful.

Non-impact printing techniques

Non-impact technologies do not require an image carrier (plate) as do the more conventional methods of printing covered so far. This unique property allows the design to be changed simply and at any point. The current dominant technologies, electrophotographic printing and inkjet printing, are described in this section.

The process of electrophotography is made up of five simple steps as shown in Fig. 19.22. Initially, the image is created using a light source that impinges onto a suitable conductive surface by altering the surface's charge distribution. An appropriately charged powder or liquid toner ink is attracted to this charged image surface and the ink is then transferred to the substrate via a further charge applied in the printing nip. The toner is then fixed to the substrate generally with heat and pressure. Finally, the

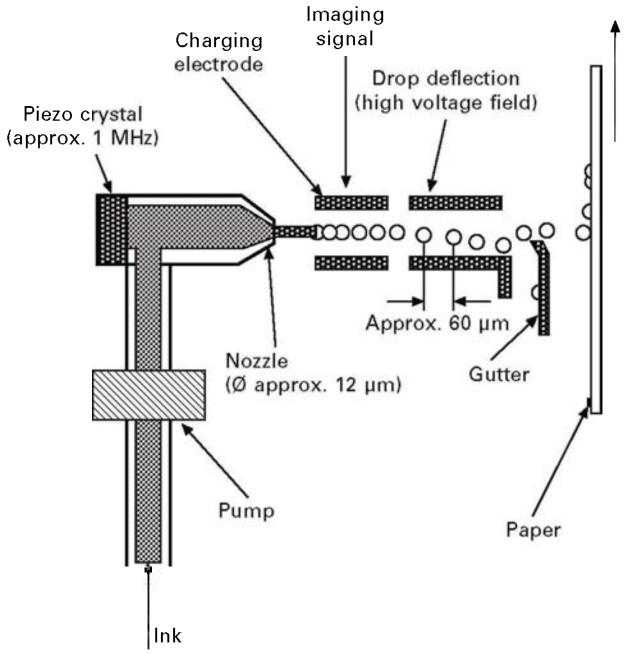


19.22 Electrophotography or xerography (from Kipphan, 2001).

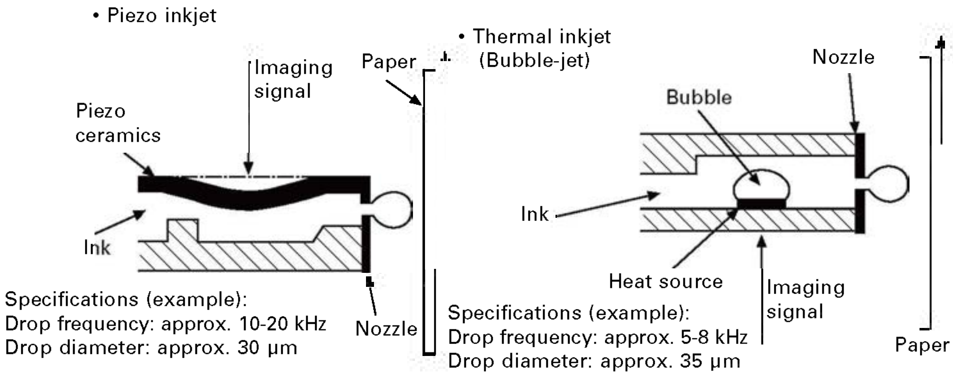
image is cleaned from the photoconductive surface. The surface is now ready to be charged with the next image (Davidson, 1995). This process is familiar to all in the form of modern photocopiers and desktop laser printers and is sometimes known as xerography.

For inkjet technology the ink is transferred directly from an ink well to the substrate. This process is controlled digitally and can be classified into two main categories: continuous technology and drop on demand (DOD) technology. Figure 19.23 describes continuous inkjet technology; the main feature is that pumping ink through a nozzle on which a piezo crystal is constantly vibrating generates a continuous stream of ink droplets. An electric charge is applied to the droplets to enable their deflection onto the substrate. Ink droplets that are not deflected onto the substrate are collected and returned to the reservoir (PIRA International, 2009).

In DOD-type inkjet systems, a drop is produced as and when required on the substrate. In piezo-type inkjet print heads, the ink well has a piezo crystal wall that, when electronically charged, deforms and forces a droplet from the nozzle. Such a system is shown in Fig. 19.24. In thermal bubble-jet-type print heads, a localised area within the ink well is super heated, causing vaporisation of a section of ink. This vaporisation causes a change in pressure within the chamber and results in the expulsion of a droplet of ink. A schematic of a thermal bubble-jet printer is shown in Fig. 19.24. Either the superheating or charging of the piezo crystal is controlled digitally according to the image data that needs to be realised. Thermal bubble-jet printers tend to be restricted to desktop applications with piezo systems more popular for industrial printing use.



19.23 Continuous inkjet (from Kipphan, 2001).



19.24 Piezo and bubble-jet technologies (from Kipphan, 2001).

The use of digital print systems for industrial print applications (outside proofing applications in Section 19.9.1) is a fast growing sector of the print industry. However, certainly in the packaging market, it has not made the impact initially expected. Digital packaging printing is expected to grow exponentially over the next 10 years; in fact the percentage growth between 2003 and 2007 in the packaging and label markets has been around 80–90% (Springford, 2007). It can be said that inkjet has been successful in making significant inroads into markets that were traditionally dominated by screen printing (printed textiles, ceramics, glass, large-scale advertisements and shelf-ready packaging) but it has failed to do so in others. The main reasons for this failure are the many requirements for specific packaging applications requiring tailored inkjet solutions. The speed of printing is considered slow compared to conventional processes, particularly for high volume work, and digital print is limited in its ability to produce large single colour areas with high colour density.

However, digital printing does have distinct advantages that with technological advancements will enable it to compete on a much greater scale in all markets. In recent times the packaging industry has seen two particular trends that suit digital printing systems. Firstly, the number of design changes and relaunches for brands is increasing in highly competitive markets; as the cost of pre-press for digital is vastly lower than other processes, it is well suited. Secondly, the reduction in batch sizes in the packaging market following just-in-time (JIT) principles also suits digital processes which can convert small run lengths quite effectively (Slembrouk, 2007). The recent developments in digital printing are clearly many, since it promises so much and is still in its infancy when compared to established processes. In terms of packaging the most significant developments are its use for individual coding of products often as an in-line process, its expansion into the flexible and carton markets, developments in the technology of the printing head allowing a vast array of ink systems to be printed and the technology designed into the inks.

19.10.4 Typical print defects

Although the printing processes discussed are markedly different, similarities exist in the type of defects that can occur, even if the cause of the defect may differ. Typical print defects are discussed in the following section, although the defects listed and typical causes are not exhaustive.

Colour variation

Colour variation is a common print fault particularly with lithographic printing. In general, flexographic and gravure have relatively stable colour since if the ink and print cylinder or anilox are in good condition, the repeatable print result should be the same; however, even though the colour consistency is more simply controlled, batch variation can be an issue as can process variation if close attention to the press is not taken by the print operator. Colour variation in lithography is typically a product of poor ink/water balance. If the balance between ink and water is not in a state of equilibrium, the tendency is for the colour (ink) and film weight to be unstable and since the film is only very thin, any minor changes can result in visible colour difference.

Hickies/splashing

'Hickies' is the industry term for dust or debris interfering with the ink transfer resulting in a small imperfection in the print (a spot with a halo around it). It is common in all printing processes and is particularly prevalent in carton production with coated boards which have inherent dust particles near or in the print surface. Other imperfections of this type may be caused by splashing of solvent, water or oil from the press itself; these are generally spots without a halo and the shape of the spot can often determine the source of the splash.

Misregistration

Misregistration is an incorrect arrangement of colours in relation to each other. It is a common fault with all processes. Areas of misalignment of colours can cause images/text to appear blurry with edges of visible single colours. The advantages of FM screening to hide misregistration are described in Section 19.7.4. There are several possible causes of misregistration, particularly in reel or web-fed applications, such as incorrect printing pressures, variable web tension, and poor plate mounting.

Scumming

Scumming tends to be an issue with gravure printing in particular and also lithographic printing. Scumming in both processes can be described as ink transfer in non-image areas, usually a patchy washed out appearance of a specific printed colour. In gravure printing the effect is a result of ink being held in the non-image sections of the cylinder and not being removed by the doctor blade. Cylinder manufacturers have done a great deal of work to reduce the likelihood of scumming at cylinder manufacture, and ink companies try to achieve the correct formulations to reduce this effect. Ink control, cylinder type and printing unit set-up are key to minimising the likelihood of scumming in gravure printing. In lithography it is an imbalance in the ink/fount relationship that is the cause of scumming. Insufficient wetting of the plate (too little fount or fount with incorrect surface tension) tends to be the cause.

Bleeding and feathering

Bleeding and feathering are two different defects, although they can appear similar on the printed product. Both phenomena appear as areas of ink transfer close to or part of a printed area. Bleeding tends to be associated with flexography and gravure printing systems and is generally a result of insufficient drying, ink film weight being too high and other ink faults such as wrong pigment choice and incorrect viscosity. Feathering is common in gravure and flexography and can generally be attributed to ink drying on the plate/cylinder prior to ink transfer, pressure settings and ink formulation issues. In lithographic printing, feathering is usually a result of ink/fount imbalance and is common with strong colour shade requiring a high level of ink.

Ghosting, repeating

Ghosting is described as a faint printed image or reduced transfer image which appears where not intended in a design. It is a defect that can occur in all of the major printing processes. It can generally be attributed to issues with the design or layout of the design, particularly in lithography. In lithography it may be a result of the blanket being embossed with a previous design and a similar effect can occur in the mesh for screen printing. With flexography and gravure processes the problem tends to be a mechanical issue (e.g. gear wear), doctor blade set-up or ink problem.

Screen clash

Screen clash is an interference pattern resulting from inappropriate screen angles being chosen in printed images or areas with vignettes running into one another. It can affect any of the printing processes which run conventional screening and is described in more detail in Section 19.7.2.

Dot gain or tonal value increase

Dot gain, as it is commonly known, is a deviation from the expected increase in tonal values for halftone printed dots. The process of fingerprinting presses for pre-press operations and proofing accuracy is described in Section 19.8.2. Deviation from the expected values can result in a reduction of detail and variation in expected colour and contrast. The effect is commonly a result of ink type and ink/fount balance in lithographic printing, although pressure, substrate and drying can also be potential causes. For flexographic processes the causes tend to be the plate, or mounting tape and pressure settings. Dot gain is less of an issue for gravure printing and tends to be a result of ink control. Errors in fingerprinting, variable unmeasured gains for special colours and errors in pre-press can also be a cause of variable dot gain.

19.11 Other processing techniques

Aside from the basic image transfer techniques described in Section 19.10.3, there are other processes often used in-line or as off-line processes to add further value and impact to the finished product. The mechanisms and uses of these processes are studied in the following sections.

19.11.1 Varnishing/lacquering

A varnish or lacquer can be described as a transparent coating applied to a printed product. Overvarnishing of printed products is a common process in the packaging industry and is carried out for a number of different reasons:

- to protect the printed product beneath, preventing rub off, abrasion marking, imparting colour protection (lightfastness) or provide a barrier to external forces and internal contact
- to aesthetically improve the appearance or add decorative effect to the product
- to provide required properties to the product for subsequent processing and its end use.

In the packaging industries varnishes tend to be applied as a liquid coating via gravure or flexographic processes. The protection properties offered are not only useful for the end user but also help to speed up production processes by reducing waiting time between handling.

Varnishes are formulated with specific properties in mind, whether they are visual or process requirements. Visual effects can simply be the level of gloss imparted on the product. A high gloss finish with incident light boundary reflection in a narrow set of directions imparts a smooth mirror-like surface and glossy appearance. In contrast, a matt finish reflects incident light in many directions. Varnishes can be formulated to have specific gloss levels. It should be noted that the gloss level can affect the appearance of colour (matt finishes tend to dilute the colour sensation) and that combinations of different levels of gloss can provide contrast in the finished product.

Other aesthetic improvements provided by varnishes are the so-called 'special effect', varnishes described in Section 19.7.4, such as pearlescent pigmented coatings. Security technologies have also been built into varnishes for anti-counterfeit purposes and tactile varnishes are now common to stimulate the sense of touch of the end user.

Property modifying varnishes may control simple processing characteristics such as slip, yet they may also be used to impart other product-specific properties such as mould inhibition in cosmetic packaging, barrier properties in primary packaging (direct contact packaging) and remelt sealing properties in blister packs and flexible packaging closures.

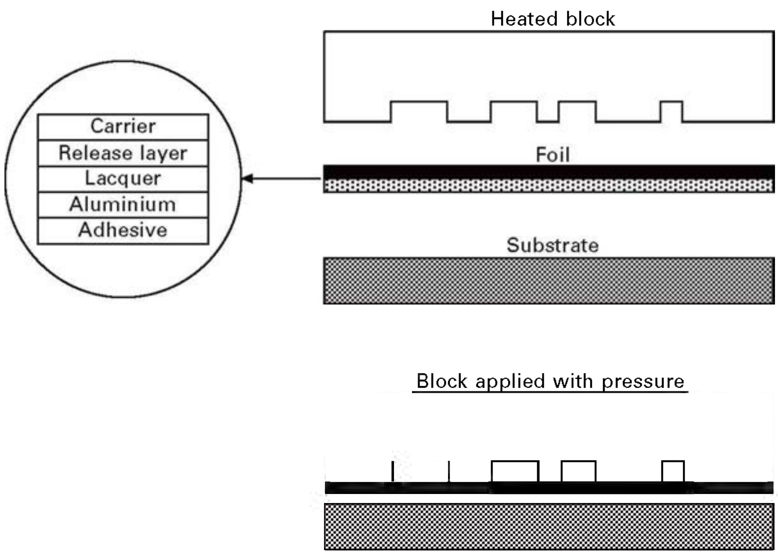
19.11.2 Foil blocking

Foil blocking is a decorative process used to transfer high lustre, mirror-like foil finishes or holographic images to a printed product. These transfer foils are available in a range of colours, and holograms can be designed and applied in the same way. Traditionally, foil blocking is a heated transfer process (Fig. 19.25) and can be either a rotary or flat-bed configuration. The heated die melts the transfer adhesive and releases lacquer in the area of impression, and the foil layer is transferred from its backing film onto the printed product.

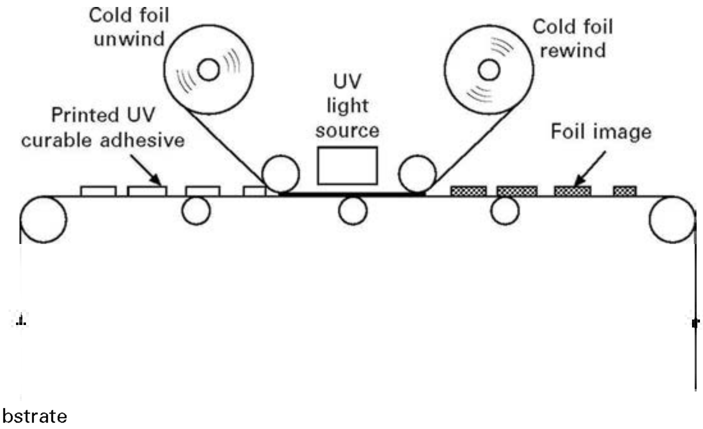
Cold foil blocking has been introduced recently and has seen increased popularity particularly in the label market because of its reduced cost and increased speed of transfer compared to its heated counterpart. The general process described in Fig. 19.26 is for a UV curable cold foiling systems, although other drying formats can be used but the web path may be altered. The limitation of cold foiling tends to be that the quality is not as high as the hot foil method, particularly for clean straight edges and fine detail reproduction. However, relatively simple designs can be processed adequately and the production efficiency benefits are considerable. Hot and cold foil blocking processes are popular in packaging for their decorative properties. They are predominantly used in the label and carton markets.

19.11.3 Embossing

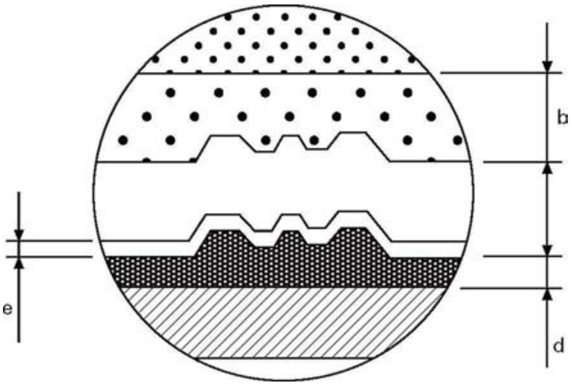
Embossing describes the process of raising areas of image/product so that they sit proud of the general surface of the product. Debossing, in which an area is recessed in specific areas, is also common and can be used in conjunction with embossing in the same product to create more enhanced three-dimensional qualities. This process



19.25 Hot foil blocking.



19.26 Cold foil blocking.



19.27 Embossing (from Bobst, 2002).

is particularly common in the carton and label packaging markets and can also be carried out in conjunction with the foil blocking process. The flat-bed method of embossing/debossing is depicted in Fig. 19.27, where the substrate (e) is depressed between male (b) and female (d) forces resulting in emboss. Rotary embossing is also common and the process is similar.

This method is also used to apply Braille to printed cartons. Embossing effects can also be created using special ink systems or with screen printing due to the large film weights it is capable of applying. Thermal or radiation expanding inks are currently not popular as they have two distinct limitations: the speed of expansion is not fast enough for packaging processing efficiencies, and they are less robust when compared to a mechanical emboss to withstand further processing. The mechanism of these systems is simply that an ink containing an active species which, when heated, expands is printed in the areas required to be embossed. At some time during or after processing, the package is heated or exposed to IR radiation to activate the expansion process. It is expected that this technology will improve to allow competition with the conventional embossing process.

19.11.4 Heat transfer printing and ceramic or glass decal

Heat transfer printing is similar to the hot foil blocking process in that it is a process by which an image is transferred by heat and impression. This method of image transfer has typically been used for the manufacture of special design clothing (e.g. T-shirts). However, more recently it has gained in popularity in the printing of large-scale fabrics, wood and metals. The process itself is a clean one since no liquid inks, solvents or drying powder are used. The increase in popularity is largely due to the improvements in manufacture of the transfers with the advent of digital print. Previously the transfers would be manufactured using the screen process which made short-run work not cost effective. Inkjet and electrophotography printing are now the dominant methods of transfer creation and have all of the benefits expected of the digital process: cost effective independent of run length, tight registration control and frequent design change flexibility.

Ceramic decal or transfer is a term given to the heat transfer process used for applying permanent images to glass and ceramics. The inks used contain reactive pigments which, when heated at high temperatures in contact with the glass or ceramic substrate, permanently bond to it. As with heat transfer prints, inkjet and electrophotographic printing are the print processes of choice for creating decals.

19.11.5 Metallising

Metallising or vacuum metallisation is the deposition of a thin film of pure aluminium (see Chapter 9) onto a substrate by vaporisation under vacuum. It is commonly used in the packaging industry to create the metallic/holographic foils used in hot and cold foil blocking processes and the metallised films applied to carton board to produce metallised/holographic substrates for printing. It can apply a metallic finish to almost any substrate. The process itself is not particularly cost effective since the scale of the process is large and it requires lots of energy to power aluminium vaporisation and vacuum enclosure.

19.12 Quality control in packaging

The importance of quality and quality control in the packaging industry should not be underestimated. The potential consequences not only in terms of lost revenue or additional costs but of consumer safety as a result of poor quality are severe. The following sections describe the requirements for production of a fit-for-purpose product, typical quality control measures and measurement techniques and details of quality control systems and their importance.

19.12.1 Specifying requirements and setting standards

The most significant aspect of setting standards for the packaging manufacturer is the communication of the requirements of the packaging. In order for a fit-for-purpose product to be supplied, every detail of the performance of the product should be investigated and understood for each manufacturing, packing, transit and end use process. In all likelihood the packaging supplier will be familiar with requirements and the relevant test procedures for their product and can both advise on specification and make provision for testing prior to and during manufacture. It is thus important to communicate all required properties for the packaging at an early stage in the development process. Table 19.3 lists some of the testing methods available for packaging products (ASTM, 2009; IOPP, 2009; PIRA, 2009). Certainly there are many other testing procedures which may be required depending on the processes and conditions the packaging is subjected to throughout its life. These tests should be an accurate reflection of performance, reliable, cost effective and, where possible, non-destructive (Stauffer, 2005).

Once the manufactured requirements of the packaging are fulfilled and relevant test procedures indicating a pass/fail response agreed, a standard for all future productions has been set. The manufacturer has the ability to ensure that this standard is upheld and product failure can be limited. Recording test results and maintaining batch samples allow for accurate retrospective analysis should a failure occur at any stage.

It is important for any packaging product that it fulfils the criteria specified and this is not simply a matter of fulfilling the technical requirements of the product's use. The Food Standards Agency (FSA) and Pharmaceutical Quality Group (PQG) are examples of UK bodies overseeing the rules and regulations regarding packaging for their specific markets. The requirement to also satisfy the EU Regulation REACH (Registration, Evaluation, Authorisation and restriction of CHemical substances) is

Table 19.3 Selection of common testing methods for packaging materials

Packaging type	Property	Test	Examples standards
All	Colour/image quality	Visual assessment, densitometry, tonal value increase testing, spectrophotometry	Often trained visual assessment only or numerical measured data comparison
All	Ink film	Tape tests, solvent rub testing, abrasion testing	ASTM F2252 ASTASTM D5264M D4752
All	Slip tolerance	Friction coefficient testing	ASTM D3108
All	Light fastness/ weatherability	Xenon arc lamp testing, daylight exposure tests	ASTM D3424 and 3794
Cartons	Carton assembly strength	Compression testing	ASTM D642, ISO 12048
Cartons	Carton erection	Opening forces for cartons	None specified
Cartons	Heat seal peel test	Seal peel test	ASTM F88
Flexibles	Flexible seal strength	Burst and seal decay testing	ASTM F2054–07 ASTM F1140
Flexibles (and others)	Barrier properties	Oxygen and water transmission rates	ASTM D–3985 and F1249
Labels	Adhesion, peel and repeel	Peel adhesion test	ASTM D3330

a legal one. The requirements set by these groups form standards that can be used to demonstrate compliance with a particular body (e.g. ISO 9001, PS 9000, GMP, PCOP).

19.12.2 Inspection processes

Inspection processes in the print production of packaging manufacturing tend either to be manual sampling and analysis or visual in-line systems for validating quality. The manual sampling technique requires a number of agreed samples to be taken throughout a production run (batch sampling); usually an initial pass must be achieved for the run to commence. The testing of these samples provides a level of confidence that the whole production run meets the required standard.

In-line visual inspection of printed material is not a new technology. It has been used in the packaging manufacturing industry for many years now and allows the quality of a production run to be monitored in real time. There are a number of technologies which have been adapted to printing processes. These are described below.

Basic photo-electric sensors

This type of sensor can be used to detect the presence of an object and is typically used in sheet-fed presses to warn the printer of missing sheets. Similarly, relatively simple contrast scanners are used to detect splices (joins) in reel to reel printing applications allowing the splice affected part to be labelled if it cannot be removed, thus acting as a warning for downstream processes. These types of sensors are also commonly used in registration systems of web-fed printing machines.

Laser sensors and scanning sensors

These more complicated systems can be used to measure incorrectly positioned product (web movement) and product outside specification tolerance (film thickness). They can also be used to scan simple codes such as bar codes. Bar codes and similar types of code are often used as a quality control for distinction of different products. Often they are added to artworks, packaging outers and pallets of product by both the manufacturer and customer to control batch traceability, remove substandard product and prevent mixing of similar products.

Machine vision systems

Simple versions of these types of systems take still images of printing material as it is running with the aid of stroboscopes (strobe lighted image capture) or from freeze frame continuous image capture. These systems allow the printer to monitor the quality during production at running speeds. They are popular in reel to reel applications and are often linked to labelling systems to allow defective areas of print to be marked up clearly so that they can be removed during downstream processing treatments.

Advancements in technology now allow for the more complex systems of optical character recognition/verification. These systems allow comparison of individual measurements against a given standard (Anon., 2009). Capable of spotting a whole host of print defects, these systems are being introduced/retrofitted to print machinery. They have gained popularity particularly in sheet-fed application with double delivery systems which allow product affected by defects to be segregated from good quality product whilst in full production in a separate delivery section of a press. However, the sensitivity of these systems may potentially add to increase wastage and labour costs for sorting acceptable defect levels from unacceptable defect levels.

19.12.3 Tracing, packing and tracking

The issue of traceability in packaging is clearly of great importance, particularly the requirement of batch traceability for food/beverage and pharmaceutical packaging. This may be performed in a number of different ways and the packaging user should have a procedure set in place to manage the traceability of their product and its packaging. Much of this can be carried out at the artwork stage of the packaging design by utilisation of individual item/product identity information that may be printed on the packaging at manufacture, e.g. product-specific barcoding, in-house item coding, formulation coding or simple printed logos. As such it is vital for packaging manufacturers to be able to manage the requirements for batch identification for their customer, the packaging buyer.

The traceability of individual batches of packaging supplied is generally also managed by similar methods depending on the customer requirements and/or the capabilities of the packaging supplier. This again may be relatively simple coding such as a bar code, date or job number via labels on outers containing a packaging product (cartons, corrugates) or labels attached to bulk packaging items themselves (label/flexible packaging reels). The relatively recent technology of radio frequency identification (RFID), which is essentially a tag that can communicate with a scanning antenna, has been used to great effect to monitor large-scale items in the packaging industry such as whole deliveries of product. In fact, this is more widespread and many products are being monitored using RFID, in particular individual products of high value such as cosmetics (perfumes) and multimedia products (CD, DVD). As a result, much research has gone into actually printing the receiving antennae of RFID tags directly onto packaging and reducing the cost of the tags themselves. It is expected in the near future that many commonplace items will include RFID technology.

In Section 19.12 fit for purpose and achieving standard requirements were discussed. The same principles also apply to the packing specifications of packaging materials, whether built into the packaging product or part of the delivery specification. It is important for the packaging buyer to specify requirements for packing and delivery of the packaging product. Also of importance is good stock management of packaging materials since packaging products may also exhibit deterioration in performance over a period of time. For example, the performance of carton board packaging assemblies tends to show a decrease in erection performance if unused for extended periods and adhesion in any glued components may be reduced or lost. Similarly self-adhesive label packaging may also show a reduction in adhesive performance over a period of time. The packaging manufacturer will almost certainly be able to provide a guide as to the effectiveness of their product over extended periods of time and are likely to specify a period of time in which they guarantee their product performance.

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20
Packaging machinery and line operations

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Abstract: This chapter gives an introduction to help build the basic understanding of the principles of operation of the main types of packaging machine. The design and operation of a packaging filling line is a complex task, calling for a multidisciplinary team, within which each will require a broad understanding, in addition to their own specialist field. It is inevitable that the study of this subject will necessitate reference to the material-specific chapters throughout this text. In addition, reference to Chapters 4 and 21 is highly recommended.

Key words: packing, filling, line equipment and design, unscrambling, filling, counting, capping, labelling, cartonning.

20.1 Introduction

The packaging line is an application of materials technology and production engineering and developments in both disciplines have contributed to innovations in packaging. It is now commonplace to see flexible wrappers and bags with tear strips or laser cuts to make them easy for the consumer to open or ingenious tamper-evident devices to give the brand owner and the consumer assurance about the integrity of the product. Complete packaging lines are now operating where bottles are moulded from resin, filled, sealed, labelled, cartonned and palletised with a high level of automatic control and inspection. Such developments have brought the need for a very wide range of packaging machinery. This means that it is impracticable to explain them all in great detail. The aim of this chapter is to give an insight into the basic operating principles and to act as a springboard from which further information may be gathered.

20.2 The packaging line

A typical sequence of activities of a packaging line is to:

- bring the packaging components from the packaging warehouse
- place the containers onto a conveyor belt which will move them through the packaging line in the correct orientation
- clean containers (e.g. if filling with food products)
- fill the product into the containers
- close the containers
- if required at this stage, check product has been filled accurately and safely
- apply suitable identification such as a label
- apply any additional packaging (e.g. a carton with a leaflet)

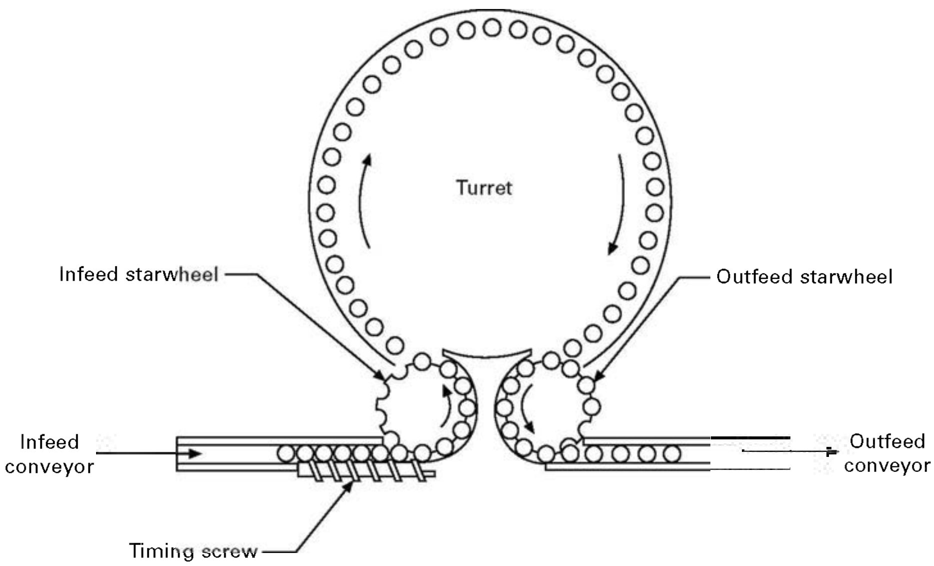
- collate the primary packs into secondary packs and palletise the secondary packs for transfer to the finished goods warehouse.

The following sections discuss types of packaging line layout and some of the common technologies used in these operations.

20.2.1 Types of layout for packaging lines

The two most common configurations for a packaging line are straight-line or linear and rotary layouts. Since they depend on each operation happening in sequence, straight-line layouts have an intermittent operation, depending on the complexity of a particular operation in the line. Filling operations are often the slowest operation in the line since they require each container to be positioned for a period under a filling head for filling to occur before the container can move to the next stage. Multiple filling heads may be used and some filling machines move the filling heads with the container to allow more continuous filling as the containers move along the packaging line. More complex machines use a dual conveyor belt system with fill heads for each line operating in sequence to provide a smoother flow of filled product. In practice, to make the most of the available space, this kind of layout may have a ‘U’ or ‘S’ shape. Conveyor belt systems take product down one section of the packaging line and then loop round for the next section.

One way of minimising delays in straight-line packaging lines is to use a rotary layout. In these systems product is fed out of the main packaging line into a rotating circle (called a turret) where a more complex operation such as filling can take place before the product is fed back into the main packaging line (Fig. 20.1). The advantage of this configuration is that the turret can process more units at a slower



20.1 Rotary layout on a packaging line.

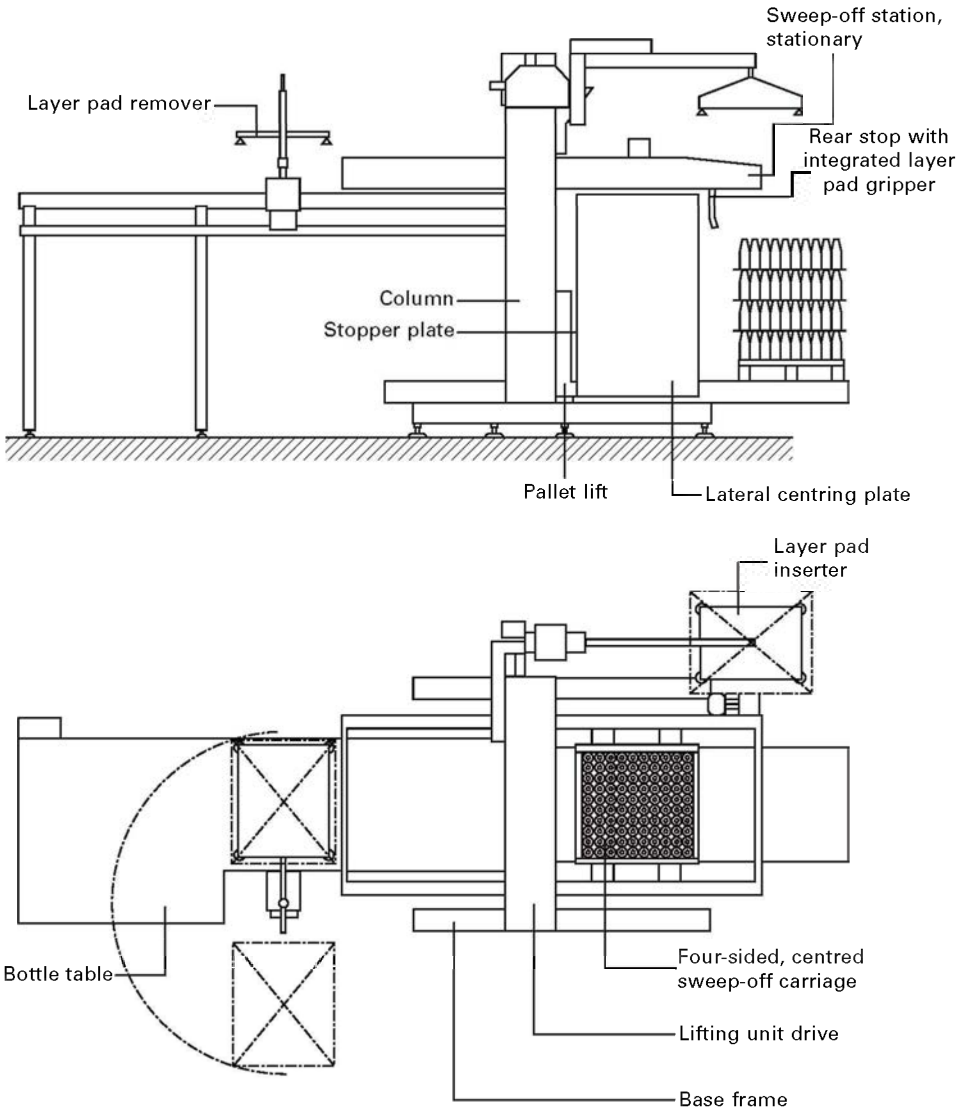
speed than the main packaging line, for example by incorporating a large number of filling heads, thus allowing a more rapid, continuous flow of product onto the next stage. Rotary machines typically use a timing screw to control the flow of product into a starwheel which diverts the product into the turret, whilst another starwheel redirects the product back into the main production flow.

20.3 Unscramblers

Typically the first operation in a packaging line is to transfer the containers to be used for the product to the packaging line. This requires moving them up to the packaging line and removing any packaging used to protect them during transport. They may also need to be sterilised before filling. The technology required depends on factors such as the type of container, how it is supplied, the degree of cleaning required (determined by the product type) and the speed at which the line is to run.

Metal cans for food and glass bottles for beer and spirits are usually filled on relatively high speed lines and the containers are delivered stacked in rows on pallets. Once any outer wrappings are removed, an automatic depalletiser takes an entire layer of containers from the pallet and places it on an in-feed table. Figure 20.2 shows a depalletiser with a sweep-off mechanism, although lift-off devices also exist. The containers are then marshalled into an orderly row. If cleaning is required, this may be done by inverting each container and blowing clean air into it, to remove any loose debris, or spraying with steam or hot water. Drying then follows (if necessary) and the containers are aligned in the correct orientation ready for filling. Rinsing with hot water is especially important for glass containers which are going to be filled with a hot product as it helps to prevent thermal shock. On the other hand, if the product is chilled at the point of filling, care must be taken that the temperature difference between the glass container and the product is not excessive. Plastic containers are normally much more durable and a mechanical means of removing containers from their transit packaging, cleaning them, orientating and supplying them to the packaging line is much easier to achieve. Cleaning may be done using hydrogen peroxide, especially if the containers are used for aseptically packed products.

Containers which are used in more modest quantities, for example glass bottles for perfumes, are usually supplied in corrugated board cases, possibly with internal divisions to provide protection against shock in transit. Such containers are likely to be loaded onto the packaging line manually, with the corrugated cases being opened as and when needed, which means that any unused stock can be returned to the warehouse and remain clean and contamination free. It may be necessary to invert each container and inject air into it to remove any loose debris, prior to filling. Whilst this means more manual labour than on the high speed lines mentioned above, this is invariably more cost effective than investing in automated handling equipment which would require several complex changeovers every time a new style of container is filled.



20.2 Automatic depalletiser with sweep-off mechanism.

20.4 Fillers and filling

Filling machines measure the product by weight, volume or count. There are several factors to consider when selecting which type of machine to use. These include:

- whether the product is a solid or a liquid
- the type of container required
- the level of accuracy needed in the filling operation.

The following paragraphs examine the various properties of solids, liquids and container types.

Solid products can be categorised in two ways:

- discrete solid items such as tablets which are often filled by counting a given number of items per container
- powders which can be further categorised by characteristics such as particle size, moisture content and bulk density.

Discrete items may vary in handling properties. Some may have varying shapes and sizes and may be fragile (e.g. crisps). They may trap air and have a tendency to settle over time. These characteristics make gentle handling necessary and filling by weight more accurate than filling by level or volume.

For the purposes of filling, powders can be sub-divided into the following types:

- free-flowing
- non-free-flowing/agglomerated.

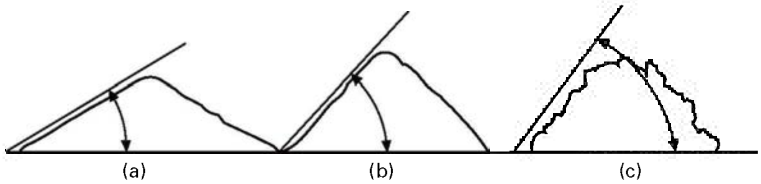
Because individual particles move freely in relation to one another, free-flowing powders or granules have a consistent density, do not trap air and pour readily. As a result they typically form a flat cone with a shallow repose angle when poured onto a level surface (Fig. 20.3(a)). This type of powder is relatively easy to handle by a range of filling machines.

Whether because of characteristics such as irregular particle shape or high moisture content, which results in particles adhering to one another, non-free-flowing and agglomerated powders do not pour easily. They tend to form a steep cone when poured onto a level surface or agglomerate with particles clumping together (Fig. 20.3(b) and (c)). They are therefore prone to sticking to surfaces and clogging passages within filling machinery. They also tend to trap air within and between agglomerations of particles which results in variations in density in different areas of the product. Because this type of product may require more force to move it, filling machines based on gravity may not be suitable. Variations in density mean that filling by volume may not be accurate and that filling by weight is more appropriate.

Liquids can be categorised in a number of ways:

- by viscosity, e.g. low-viscosity, free-flowing liquids, viscous semi-liquids and highly viscous 'semi-solids'
- by other characteristics such as surface tension which may result in behaviour such as frothing or foaming when agitated.

These characteristics determine what type of filling operation is feasible and will



20.3 Angles of repose: (a) free-flowing solids; (b) non-free-flowing solids; (c) agglomerated products.

result in an accurately filled container. Some products (e.g. soups) may contain a mix of liquid and solid components and these will usually be filled separately with the solids filled first, followed by the liquids.

Another basic factor in selecting the type of filling machine is the type of container to be filled. Containers can be categorised as:

- rigid
- semi-rigid
- flexible.

Rigid containers made from glass, metal or thick plastic can withstand the application of a vacuum or high pressure during filling. Semi-rigid containers such as many plastic bottles or yoghurt pots are not able to withstand the same level of stress. They may bulge under pressure or collapse if a vacuum is applied. This will result in potential damage to the container, inaccurate filling and poor sealing which may have a major impact on product safety and quality. Flexible containers such as tubes for toothpaste may, on the other hand, require insertion of a feed line into the bottom of the tube and the application of pressure to push the product into the tube so that it is properly filled without trapping air.

Filling operations must meet the legislation and quality standards relevant within the country in which the product is to be marketed, with an adequate validation of the process capability of the filling system, and adequate sampling and measurement checks to ensure that each batch is correctly filled. See Chapter 4 for more information. Another regulatory consideration is the ingredients lists which may be required to be shown on the pack. If ingredients are sold by weight, the filling system must ensure an accurate weight is consistently delivered to each container. If a high level of accuracy is required (e.g. in pharmaceutical products where exact dosages may be critical to patient safety), the filling system must be capable of the precision required. In the case of high-value products, a high level of accuracy in filling may also be critical to the profitability of the business. Over-filling or a high level of wastage can be extremely costly. If a product consists of a mixture that may not be relied upon to remain consistent during the filling process, it is necessary to fill the various ingredients separately to ensure that accurate amounts of each ingredient are delivered to the container. This is known as sequential filling, and explains why all the cherries are at one end of a can of mixed fruit salad. In some products (e.g. bottles of milk), customers will judge the accuracy of filling by level and will expect that level to be consistent between different containers.

The maintenance of food quality over the required shelf-life of the product can depend largely on removal of air from the container and adequate sealing. The filling process needs to meet these objectives if it is not to reduce product quality. In hermetically sealed glass or metal containers used for heat-sterilised foods, for example, a headspace is needed above the food to form a partial vacuum. This reduces pressure changes inside the container during processing and oxidative deterioration of the product during storage. When filling more viscous liquids such as pastes, for example, it is very important to prevent air from becoming trapped in the product which would reduce the headspace vacuum.

20.4.1 Filling solid products

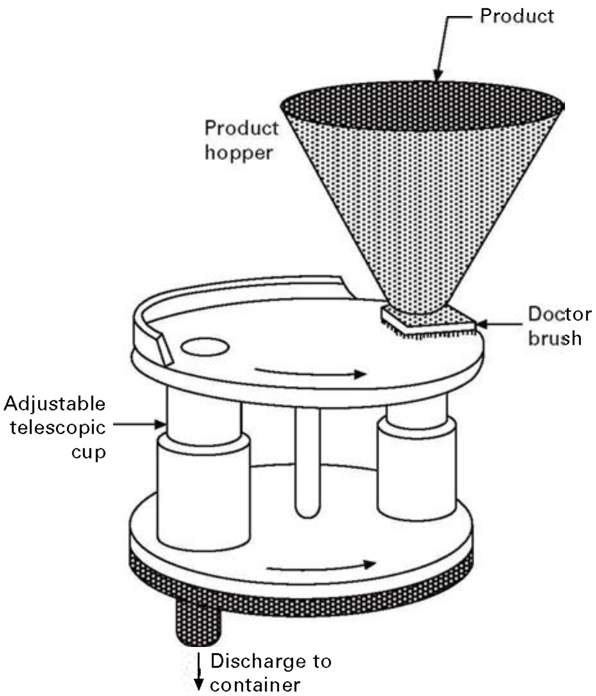
Solid products are filled into containers by:

- volume
- weight
- count (for unit items such as tablets).

Filling by volume

The simplest form of volume filling machine consists of a device for holding open cups which are filled in turn as they are passed under a hopper. A typical design involves a circular plate which revolves to present each cup under the product hopper in turn (Fig. 20.4). Scrapers or brushes (called 'doctor' brushes) wipe over the top of the cup to level off the amount of product in the cup. The cups then move to a discharge point where they tip their contents into the final container. An alternative system uses trap doors under each cup to release the product directly into the container. Some systems use adjustable telescopic cups which can be opened to accommodate a larger volume of product in each cup. These systems are suitable for free-flowing solids of consistent density. It is important to maintain a constant level in the product hopper feeding the cups since this maintains an even flow into each cup.

Some volume filling systems make use of a vacuum in addition to gravity. As the product flows from the hopper into the cup, a vacuum pump draws out air to



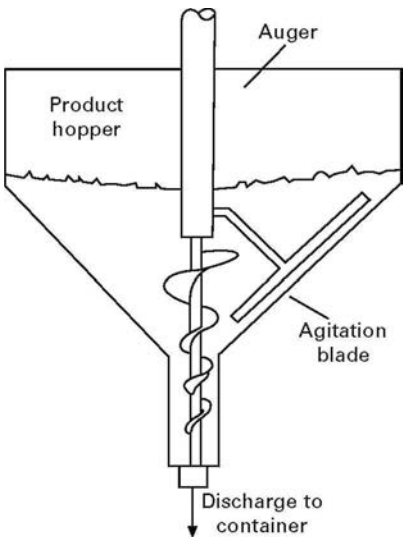
20.4 Solid products: filling by volume using a cup filler.

compact the product. A fine mesh prevents product escaping. The cup then delivers the compacted product to the container. This technique is suitable for light powders (e.g. cocoa powder) which might otherwise trap air and lead to inaccurate filling and reduce shelf life through oxidation.

An alternative to the use of cups is auger filling. A typical auger filler consists of a hopper with a funnel or tube at the bottom. An auger or screw runs through the middle of the hopper together with an agitation blade (Fig. 20.5). Towards the bottom of the auger each turn of the screw (or flight) is calibrated to a precise volume. As the auger rotates, the agitation blade rotates in the opposite direction to remove air, homogenise and then feed the powder into the flights. As the powder enters the lower flights of the auger it is divided into separate doses defined by the volume of the flight which can then be delivered to separate containers. Tapered augers can be used to compact finer powders. Auger filling is particularly suitable for non-free-flowing solids, e.g. moist brown sugar. It is not appropriate for solids with variations in bulk size or particle size and distribution, or where precise doses are required, where weigh filling may be more suitable.

Filling by weight

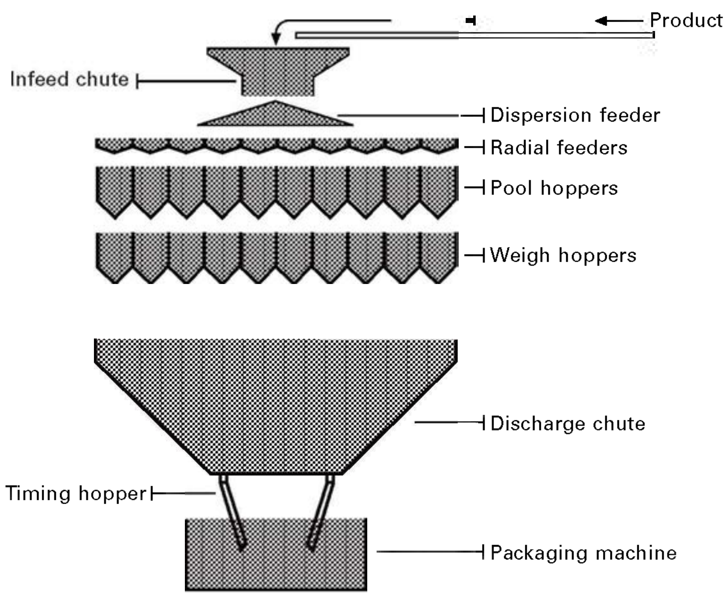
Weigh filling typically involves the use of weigh buckets. Product is fed from a hopper into the bucket. Once a certain weight is reached, the hopper is closed and the bucket tips the product into a discharge chute or directly into the container. In older machines this would be done using a mechanical balance system that would trip a mechanism to stop the feed of the product when the required weight had been supplied. The container supply mechanism would then release the filled container and position an empty one ready for filling.



20.5 Solids products: filling by volume using an auger filler.

One potential problem with weighing is the risk of surplus product reaching the bucket after the bucket has reached the desired weight but before the flow of product has been halted. This can be dealt with by having separate bulk and 'dribble' feed lines. The bulk feed line supplies the product to the bucket until the required weight is nearly achieved. The bulk feed line is then closed, leaving the slow-flowing dribble line to top up the bucket. These systems ensure greater accuracy but make weigh filling a relatively slow process.

The development of electronically controlled magnetic force balances has now made it possible to have much more sophisticated, rapid and flexible systems. It is now possible to have a multi-head machine which fills products (e.g. items of fruit) into several containers simultaneously (see Fig. 20.6). These systems often use several weighing stations to fill each container, selecting which stations to use to fill the container to the exact weight. As with more traditional systems, they use bulk feeders to fill containers to near their final weight and fine feeders to top up the container to an exact weight. The machines weigh each container so that they can allow for slight variations in container weights. This allows them to weigh either the product without packaging (net weight) or the product plus packaging (gross weight). The machine can then calculate how much each container requires, weigh each piece being supplied, and select which container to place it in and calculate continuously how much more needs to go into each container as it fills. Any packs with the wrong weight are rejected. Free-flowing powders can be measured by volume using a telescopic measuring section of the machine which is filled before the product is transferred to the container.



20.6 Solids products: multi-head filling by weight.

Filling by count

For some products, such as tablets or capsules, the amount of product is declared by count. Machines which fill by count normally use mechanical or photo-electronic systems. Mechanical counting systems usually place the product over a plate with an appropriate number of holes of suitable size. Once each hole is filled, the excess product is wiped off the plate and the product counted by the plate is then released into the feed system and into the container. The counting mechanism of a tablet blister-packing machine (see later) works in a similar way, using the thermoformed holes in the plastic film as the counting mechanism. Some systems consist of a series of thin perforated slats which pick up product as they move up through the product hopper. The slats then move down the front of the machine to enable inspection to ensure each hole contains a product. The product is then ejected into feed chutes which fill each container.

Photo-electronic counting systems usually involve tumbling or vibrating the product to create a flow of single items which move past the photocell on a conveyor belt for counting. The photocell counts each shape as it passes, typically by identifying its shadow. Once the required number is reached, a gate diverts the counted items into a feed chute which fills the container. These electronic systems can now also measure the size of the shadow to ensure that it is not too small (e.g. a broken tablet) or too large (two tablets together). In order to improve the detection capability of these systems, the wavelength of the light used may not be in the visible spectrum (i.e. ultraviolet or infrared). Other electronic detection systems (such as capacitance) may also be used. Modern systems can also be used to create sets of different items, e.g. mixes of nuts and bolts to be packed into sachets for furniture self-assembly kits. The machines are programmed to identify different shapes and sizes, separate out specific items and combine them with others of a different shape and/or size to create each set.

20.4.2 Filling liquid products

As has been noted, there are several criteria to consider in filling containers with liquids, including:

- the properties of the liquid, e.g. viscosity, foaming capacity, particulate size
- the conditions required for filling, e.g. temperature.

In any filling operation it is necessary to give some consideration to the differing handling properties of the product. At first thought, liquids may be considered to be easy, but variations in their properties may give rise to problems and these require solutions in the type of filling machine used and/or the design of the packaging. For instance, a viscous liquid such as jam may have to be heated to enable it to be filled. In this case the jars have to be manufactured and tested to ensure that they are able to withstand the thermal shock of being filled with the hot product. The extent of thermal shock has to be controlled (see previous discussion) and the pumps and other components handling the liquid and the container have to be constructed of materials capable of withstanding the heat. The machine has to exert sufficient force in its operation to move a more viscous liquid such as jam compared to a low viscosity liquid such as fruit juice.

Another product characteristic to consider is low surface tension in some liquids, causing the product to froth when filled. Some types of filler cause less turbulence to a liquid than others and are, therefore, better suited to liquids prone to foaming. Frothing or foaming may also be reduced by having nozzles which penetrate into the container and either cause the product to flow down the inner sides of the container, or direct the product below the filling level. These requirements can make the machines more complicated and more expensive both to build and maintain.

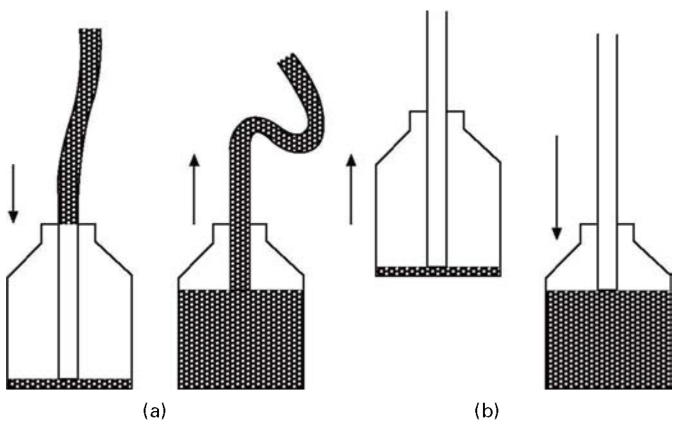
There are three main ways of filling liquids:

- by level
- by volume
- by weight.

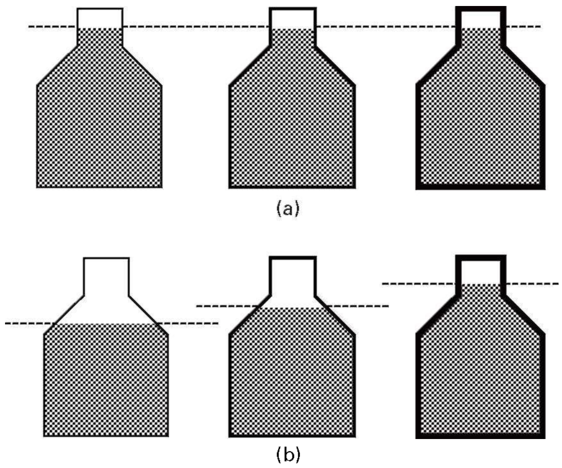
Within these three types, filling can be done either from the top or the bottom of the container. Top filling involves inserting the filling tube into the neck of the container and either allowing the liquid to drop to the bottom or directing the liquid to run down the container sides. The latter will minimise turbulence and air entrapment. Bottom-up filling involves inserting the filling tube down to the bottom of the container and gradually withdrawing it as the container fills. This can be done either by moving the tube itself (Fig. 20.7(a)) or raising and lowering containers on the packaging line (Fig. 20.7(b)). Bottom-up filling is particularly effective in minimising air entrapment, limits frothing or vapourisation of more volatile liquids and is particularly suited to filling flexible containers such as sachets.

Level fillers

Level fillers use the container's volume to measure the amount of liquid filled. Since containers of the same design will have differing volumes due to slight variations in dimensions and wall thicknesses (Fig. 20.8(a)), this form of filling is less accurate than



20.7 Liquid products: bottom-up filling to minimise foaming.



20.8 Liquid products: (a) filling by level; (b) filling by volume.

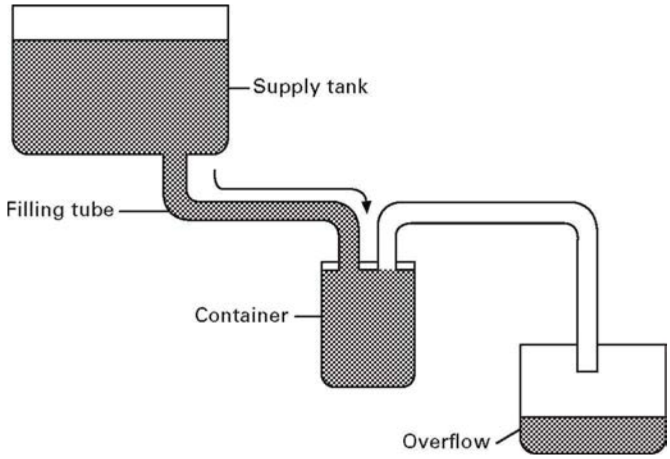
volume or weight filling. It is therefore used for lower cost liquid products such as soft drinks, beer and sauces where accurate volume is less important than a visually constant fill level. In many cases (e.g. milk, as already mentioned) customers will expect a container to be filled to a certain level and for that level to be consistent between containers even if that means there are slightly differing volumes in each container.

Modern level filling systems use sensors to identify when the right level of liquid has been supplied. Pneumatic systems use a flow of low pressure air in a tube next to the filling tube. As the liquid reaches the correct height, back pressure in this second tube triggers a valve to close off the supply of liquid. More advanced sonic systems use high-frequency sound waves which bounce off the surface of the liquid. The changing pattern of sound waves as the liquid reaches the desired height closes the valve to prevent the target level being exceeded.

There are three main types of level filler:

- gravity fillers
- vacuum fillers
- pressure fillers (also known as over-pressure or counter-pressure fillers).

In basic gravity fillers the liquid flows from a supply tank into the container below (Fig. 20.9). The height of the supply tank above the container determines the flow rate. A typical design involves a filling tube with a valve connected to a spring-loaded outer tube that fits over the container neck. As the container is raised, it activates the spring to open the valve to fill the container (Fig. 20.10). In some systems a sensor identifies when the liquid has reached the top of the container and closes the valve. In others each valve is independently timed by a control computer to deliver the target amount to the container. Any excess can be channelled into an overflow tank. Gravity filling is a relatively cheap process but is slower than vacuum filling. It is particularly suited to liquids prone to foaming since there is less agitation during filling. Bottom-up filling can be used for very foamy products. It is also suitable



20.9 Liquid products: basic gravity filling.

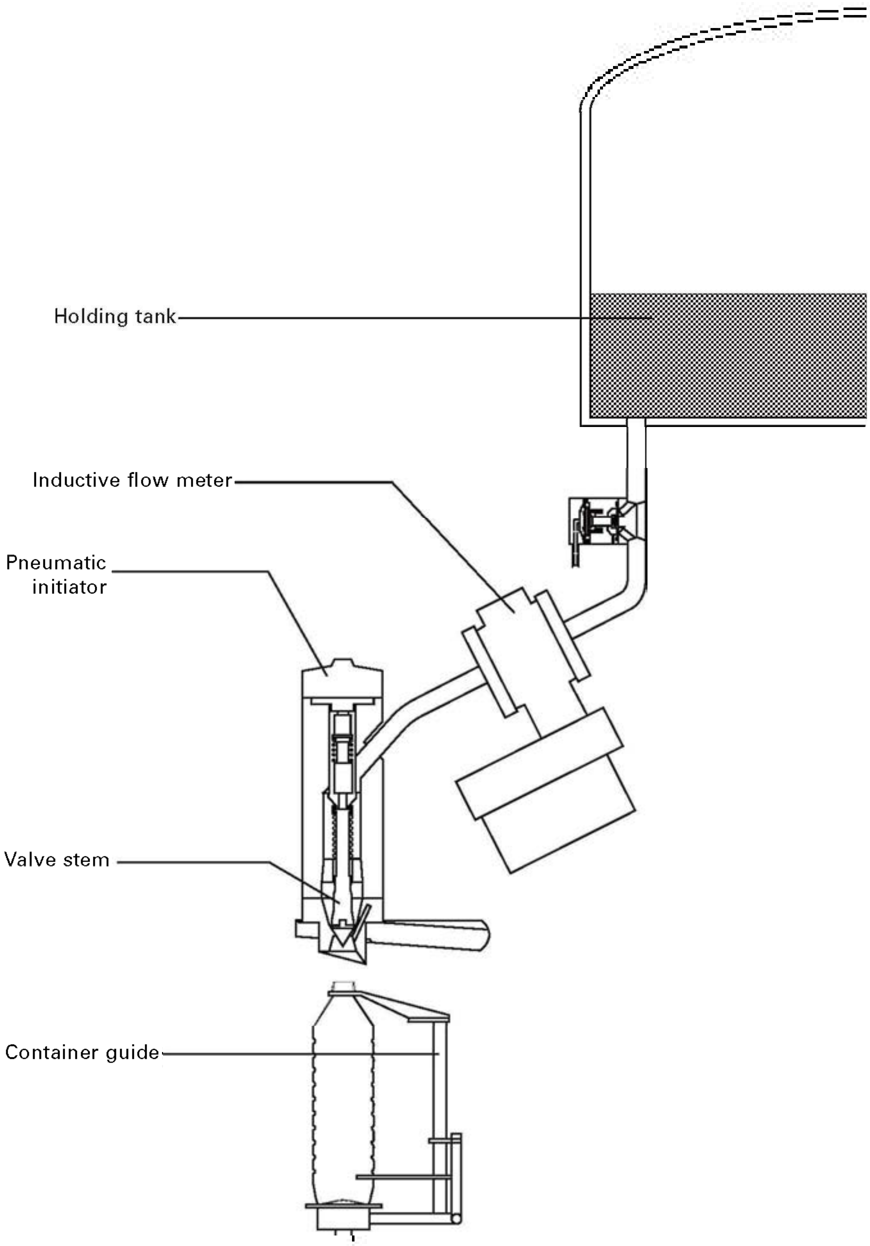
for a wide range of container types. This type of filling is less suitable for viscous, slow-flowing products or products containing large particulates.

Vacuum fillers typically work by lowering a filling tube and a vacuum line (connected to a vacuum pump) into the neck of the container and then sealing the neck (see Fig. 20.11). Air is then drawn from the container to create a vacuum using the vacuum pump. Liquid is then drawn from a supply tank through the filling tube into the container. When the liquid reaches the vacuum line, suction draws it into an overflow tank, ensuring the desired level is not exceeded. The surplus liquid can then be returned to the supply tank. An alternative approach involves keeping the supply tank initially at low vacuum to draw the liquid in. The pressure then equalises, allowing the liquid to flow into the container by gravity. As with other systems, vacuum fillers also use sensing devices to identify when the desired level has been reached, halting further flow until the system is ready for the next container. Vacuum fillers are fast, flexible and relatively low cost. They are, however, limited to rigid containers (e.g. glass bottles) which are not distorted by creating vacuum conditions in the container and to liquids which are less susceptible to aeration.

Pressure filling uses a pump to move the liquid from a supply tank to the container (Fig. 20.12). In over-pressure or counter-pressure machines, the supply tank is kept at high pressure, forcing the liquid through to the container. The fill level is determined by the vent tube inserted into the container. When the liquid reaches the vent tube, the supply is interrupted by the difference in pressure. Alternatively, the difference in pressure can also be used to draw off any surplus liquid into an overflow tank. Pressure filling is relatively fast and is suited to viscous products which need minimum agitation.

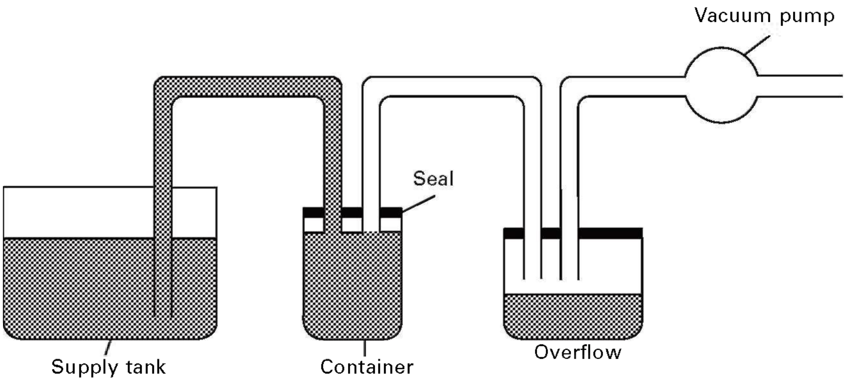
Volume fillers

In volume filling, a measured volume of liquid is placed into the container. This means more accurate measuring than level filling but may result in variations in

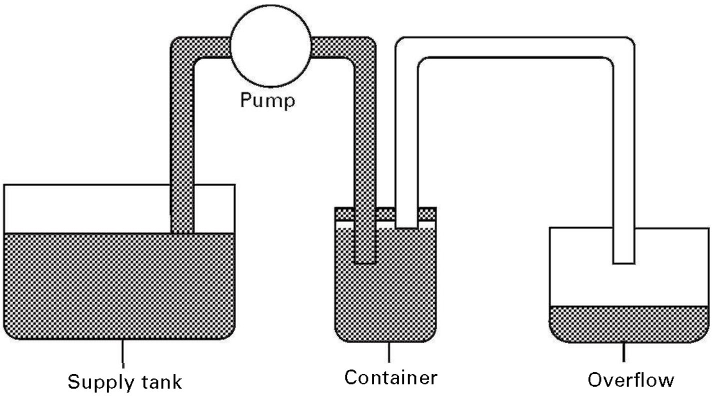


20.10 Liquid products: gravity filling using flow meter and valve.

the level of a liquid in containers, depending on variations in container size (see Fig. 20.8(b)). This will be obvious to the consumer if the container is transparent, although this can be obscured by the careful application of a neck label. Volume filling is used for high-value products and particularly for products sold by weight or where accurate weight or volume is important (e.g. pharmaceutical products where accurate dosage may be critical).



20.11 Liquid products: vacuum filling.



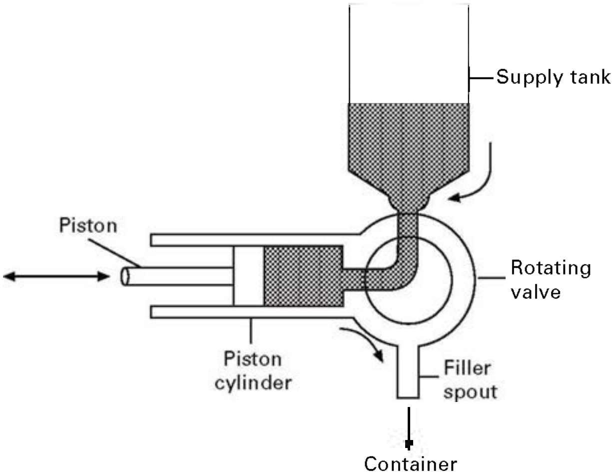
20.12 Liquid products: pressure filling.

The three main types of volume filler are:

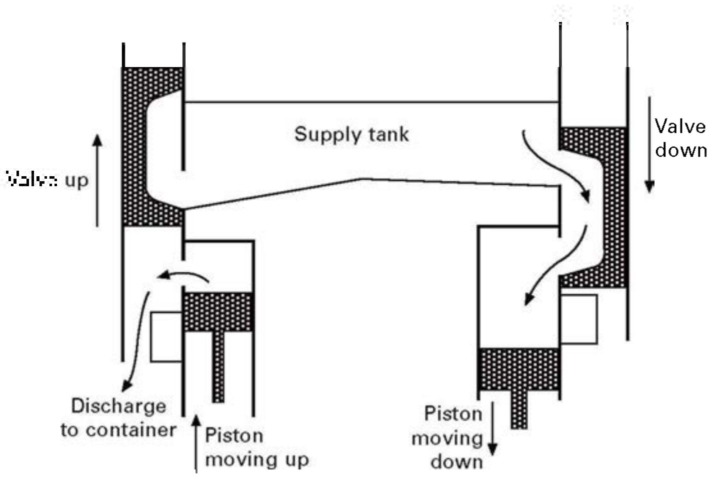
- piston
- cup
- flow: time-pressure or flow meter.

The basic type of piston filler is the piston force-pump, which is connected to an adjustable crank, driven by a control system similar to the parking mechanism of a car windscreen wiper (Fig. 20.13). When the pump is activated, the crank makes one full turn, delivering the contents of the piston to the container, and then re-filling the piston in readiness for the next container. The amount of product supplied is controlled by the size of the piston cylinder and the stroke which is adjusted by the setting of the crank. Piston fillers typically have a control device which prevents the piston turning if there is no container ready to be filled.

Piston fillers are typically fully automated with groups of positive action rotary pumps working in sequence (Fig. 20.14), with electronically controlled drives which regulate the number of turns the pump makes to provide product to each container and which allow adjustments to be made without stopping the machine. A control



20.13 Liquid/paste products: filling by volume using a piston filler.



20.14 Piston filler using automated rotary pumps.

computer tracks the number of rotations of the pumps to determine precisely how much product has been filled. When the target fill volume is reached, the computer stops the pump. Piston fillers can be used for low viscosity liquids but there can be problems in leakage between the piston and the cylinder. Piston fillers are usually the most cost effective, rapid and accurate way of filling viscous products such as jams. As an example, pastes can be filled into tubes using piston fillers. The product first has to be drawn into the measuring cylinder. The machine nozzle fits into the tube so that the paste is pushed off the nozzle as it is filled, thereby minimising the amount of air trapped inside the tube.

In cup fillers the liquid product flows from a supply tank into a measuring cup. Once this is full, the measured quantity of liquid is emptied into the waiting container. Time-pressure controlled fillers divide the liquid into portions using a valve which are then fed to individual containers. It is important to keep a steady supply of liquid to ensure accurate measurement. This means maintaining a constant pressure and temperature as well as consistent viscosity in the liquid.

Flow meter filling machines use meters which control the opening and closing of measuring valves. Meters measure the liquid in a number of ways, including measuring its conductivity or mass. These machines typically use positive displacement pumps or constant output impellers.

Weighing fillers

Weighing fillers for liquids typically use scales which weigh the desired quantity and then open and close a valve for filling the container. Net weight liquid fillers are suited to liquids that are filled in bulk quantities or smaller amounts of products that have a high value and are sold by weight. Filling by weight is suitable for liquids of varying consistencies. The advantage of this type of filler is a high level of accuracy; the disadvantages are the high cost per filling head and the relatively slow rate of filling.

20.5 Closing and sealing of containers

As discussed in Chapter 15, closures for containers have a variety of functions and there is a wide range of types and methods of sealing which are covered in more detail there. This section considers some of the basic types and how they are applied to a container on an automatic packaging line.

20.5.1 Push-fit closures

Push-fit closures fall into two types: those in which the closure is pushed *in* the open neck of the container, e.g. a wine cork, and those in which the closure is pushed *on*, or over the outside of the top of the container, e.g. the metal lid on a tin of biscuits or the plastic overcap sometimes supplied as a resealable feature on metal containers for dry products such as ground coffee.

On the packaging line, the application of push-fit closures is a relatively simple process and typically involves positioning the closure on the container which then moves under an inclined belt which presses the closure into place as the container moves under the belt. For products such as wine, the corked neck may then be covered by thin metal or plastic to provide further protection as well as decoration.

20.5.2 Screw-threaded closures

Screw-threaded closures (which can be manufactured from metal or plastic) have a thread on the inside which must be matched up with the thread on the neck of the container. Closures are typically fed down a chute to land on filled containers which have been spaced out at regular intervals. A chuck then rotates the closure onto the neck of the container until a pre-programmed torque (tightness) is achieved. Some container designs include a rim which prevents the closure from being tightened beyond a certain point. The chuck then releases, allowing the sealed container to move to the next stage.

It is essential that the neck dimensions of the closure and container match to allow efficient engagement to provide an effective seal. Thread engagement refers to the number of turns required for the closure to fit completely on the neck of the container. The greater the thread engagement, the tighter the seal and the more effective the tightening torque in keeping the closure in place. The correct torque is also essential. If too tight, the closure and container might be damaged or customers might not be able to remove the closure. If too loose, the closure might loosen, allowing air in or it may come off completely due to vibration during transit.

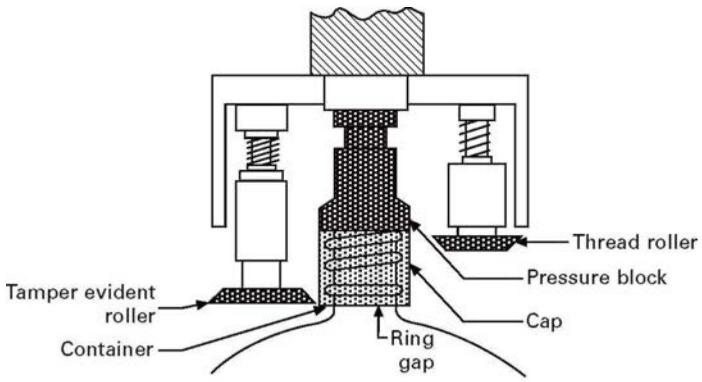
A further consideration is the materials used. Thermoplastics such as polyethylenes are vulnerable to creep, i.e. they gradually deform under stress and will therefore gradually lose torque. This may mean increasing thread engagement and application torque as well as allowing for a potentially shorter shelf life. Polypropylene is widely used for multi-use screw-threaded closures due to its good resistance to creep.

Screw-threaded closures can be wadded or wadless (see Chapter 15) and the latter may be enhanced by the use of a membrane sealed across the neck of the container. An essential requirement for this type of seal to function correctly is that there must be a metal layer included in the membrane (usually aluminium foil). The cap, with the membrane inside, is screwed on to the filled container, which is then passed between induction heating coils. The aluminium foil absorbs heat, which softens the polyethylene layer, which in turn bonds to the neck of the container, thus providing secure containment and tamper evidence.

Induction sealing systems require careful attention in setting the correct operating parameters for the torque applied by the capping machine to the seal, the position of the electro-magnetic head and the amount of energy supplied, as well as the speed of the track (which controls the time during which the electro-magnetic energy is applied to the container). It is also necessary for operating personnel to remove metal items such as jewellery before working near such machines as these items act like a transformer and could cause serious burns to the fingers, ears, etc.

20.5.3 Roll-on pilfer-proof (ROPP) closures

This type of closure is typically made from soft-temper aluminium with a partially perforated ring (or skirt) at the lower edge of the closure, and is typically supplied fitted with a wad (see Chapter 15). The closure is positioned above the neck of the container which includes a thread and, at the bottom of the thread, a ridge (known as a ring grip) to take the perforated ring. The head of the capping machine is lowered, bringing the wad into contact with the top of the container. A thread is then formed from the outside of the closure using rollers which force the soft aluminium to take on the thread form of the container (see Fig. 20.15). The perforated ring is closed around the specially formed ring grip on the neck of the container and this provides the tamper-evident feature, as these perforations are broken when the closure is unscrewed. The pressure required limits this type of closure to use on containers



20.15 Application of a metal ROPP closure.

with rigid neck sections, e.g. glass bottles, or injection blow moulded plastic bottles which are specially designed for this use.

Plastic tamper-evident closures with breakable rings are applied as conventional screw-threaded closures. Extra pressure is required to push the perforated ring at the bottom over a ridge around the neck so that it snaps into a specially designed groove which holds it in place.

20.5.4 Lug, press-on twist-off and crimped or crown closures

These three types of closures are simpler than screw-threaded or ROPP closures. Lug closures include lugs or protrusions on the inner edge, designed to engage with an interrupted thread on the container neck (see Chapter 15). They are secured by placing on the container, exerting a downward pressure and twisting so that the lugs slide under the thread to hold the cap in place. Because less rotation is required, they can be applied at a higher speed than screw-threaded closures. Given the stress exerted on both closure and container, this type of closure is usually manufactured from heavy gauge steel and is restricted to rigid containers such as glass.

Press-on twist-off caps do not always require lugs but often include a thread. First used for baby foods, they commonly include a soft thermoplastic seal and rely on a partial vacuum in the container (developed when the hot-filled product cools down) to keep the lid in place. Crimped closures, also known as crown corks and widely used on bottles of beer, are made from heavy gauge metal and have a sealing material inside (commonly a flowed-in liner of soft plastic material around the inner circumference). The closure is placed over the neck of the container, often using magnets, and the outer circumference is crimped around the lip of the bottle, to secure it in place.

20.5.5 Can closing

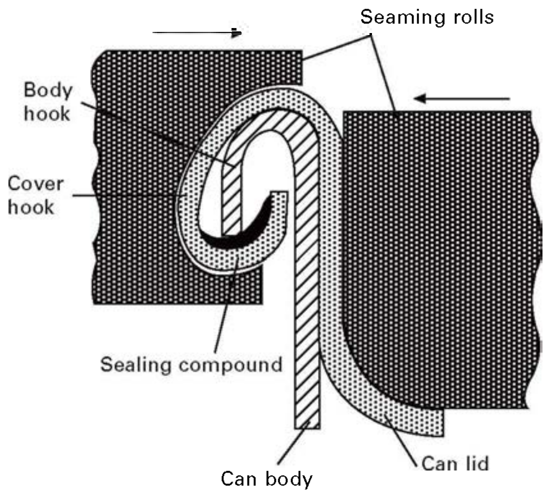
Can manufacture (including closing) is discussed in detail in Chapter 8. Only a brief summary is given here. Can lids are sealed by a double seam. Lids are typically placed on cans immediately after filling. As the lid goes on, carbon dioxide may be blown over the can to displace the air at the top of the can if a product is likely to suffer from oxidative or microbial spoilage. Each can and its lid are then raised against a sealing head. One seaming roller bends the outer edge or hook of the lid round the can rim or hook (Fig. 20.16). An airtight double seam is obtained by pressing the two hooks together with a second seaming roller. A sealing compound (typically a water-based latex emulsion or synthetic rubber compound) incorporated on the lid rim completes a hermetic seal following tightening. Since the seam is the weakest part of the can, seams are routinely inspected, often using x-ray technology to identify defects.

20.6 Labelling

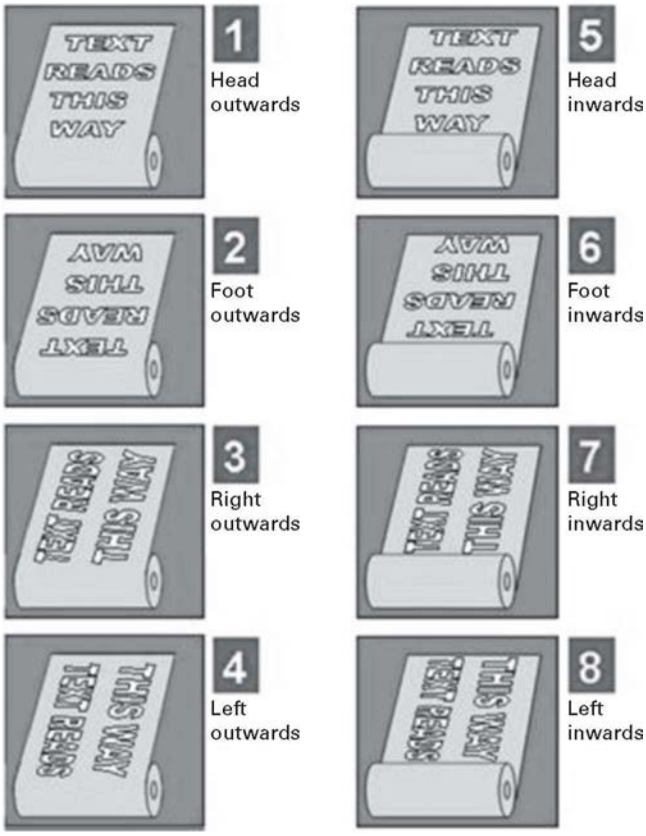
Whilst many containers are produced with decoration and identification requirements already pre-printed, many high volume products require the application of labels as part of the packaging line. Even when packaging has been pre-printed, there is often the need to apply a label to provide additional information such as shade or flavour variant. Chapter 17 provides information on the different types of labels available and the materials commonly used for labels, and an overview of label application methods. This section is confined to providing more explanation of the requirements of automatic label application. Chapter 16 on adhesives should also be referred to at this point.

20.6.1 Applying self-adhesive labels

Self-adhesive labels are provided already cut out and on rolls of silicone-coated backing paper (Fig. 20.17). Only one of the different possible orientations of the label on the roll will be suitable for the particular application and thus this must be



20.16 Seaming of metal can end.



20.17 Layout options for self-adhesive labels.

clearly stated in the label specification. Other important features determined by the labelling machine include the diameter of the core around which the roll is wound and the maximum overall diameter of the roll.

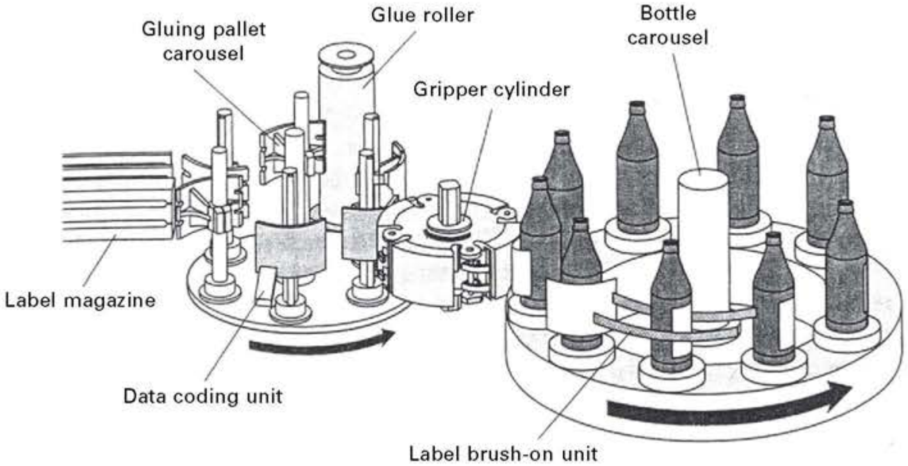
A self-adhesive label applicator works by pulling on the backing paper using a rubber roller gripping onto a capstan. When a container is detected by a photoelectric device, the capstan begins turning and pulls the backing paper around a tight radius on a piece of metal known as the dispensing beak. The speed of the label and the speed of the container are matched so that the label comes off the backing paper and is wiped onto the container using a brush to press it home. If the container is cylindrical, it is turned and the label pressed down using a wrap-around mechanism (comprising a belt running at twice the speed of the track which presses the container against a soft rubber-faced stationary plate). Another photoelectric device detects when the end of the label has been reached and the capstan stops, awaiting the arrival of the next container. This stop signal is also used to trigger an on-line coding system, if required. In general, self-adhesive label applicators are flexible and relatively easy to adjust for different shapes and sizes of containers.

20.6.2 Applying ungummed labels

Ungummed labels are usually delivered to the packer-filler in stacks which fit into the appropriate magazine on the labelling machine. It is vital that the labels are easily separated so that only one is picked from the stack at a time. Defects in the cutting dies used in label production may lead to uneven edges which can hinder this picking-up operation, as will any edge damage incurred during transit to the packer-filler.

Applying ungummed labels, does, of course, require the packer-filler to select the most appropriate adhesive for the label substrate, applicator type and machine speed. When using water-based adhesives, it is important that the labels are printed onto the appropriate grade of paper and in the correct direction of the grain (the direction in which the fibres in the paper line up on the paper-making machine). If not, the moisture from the adhesive will cause the paper to curl with sufficient force to lift the edge of the label from the container before the adhesive has had time to set. The simplest way to test the direction of grain of a paper label is to wet it. The label will curl into a tube with the straight length of the tube indicating the grain (i.e. machine) direction. Usually, but not always, the grain direction is parallel to the base of the label.

Machines which handle ungummed labels include those which apply hot-melt adhesives, often used to label cans and cylindrical plastic bottles. Here the can (or bottle) is rolled along a set of rails and a vertical bead of hot-melt adhesive is applied. This picks up one edge of a label from a stack. The can rotates, wrapping the label around its circumference and a further bead of adhesive is applied to the trailing edge of the label to hold it in place. Where water-based adhesives are used, e.g. in applying labels to bottles in the drinks industry, there is often a complex series of pallets, adhesive applicators and pressure systems used to apply the labels (Fig. 20.18). Labels can be applied to the front, back and neck area of the bottles,



20.18 Automatic application of ungummed labels (courtesy of Krones).

all at the same time, ensuring excellent alignment of labels both to each bottle and to each other. Such machines tend to be bespoke systems which require extensive modification for each bottle shape, although modern developments have concentrated on making changeovers less complex and therefore less time consuming.

20.6.3 Applying sleeves

Shrink sleeves are typically made from heat-sensitive thermoplastic film. They are normally supplied as a flattened welded tube, printed on the inside of the sleeve, to prevent damage by scuffing, and wound onto a cardboard core. A register mark is incorporated into the print which indicates to the machine where to cut off the section required. The required length of sleeve is placed over the container and positioned correctly. It is then heated, either using jets of wet steam or hot air, to shrink the sleeve to the profile of the container. If necessary a strip of hot-melt adhesive may be included onto the inside of the sleeve which holds it on to the container to ensure that it does not slip during this process or later during transit, since shrink sleeve materials are prone to creep (the tendency to deform under prolonged stress) which may loosen them over time. In designing the graphics of the sleeve, it is important to compensate for the distortion which will result from the differences in shrinkage across the profile of the container, and to ensure that any bar code symbols are subject to the minimum of distortion. The selection of the grade of sleeve film with the appropriate shrink characteristics is critical to the successful operation of this process.

An alternative means of application involves printing and then applying the sleeve using the same technology as for a self-adhesive label. This sleeve is then shrunk to fit the container by passing the container through a heat tunnel. Another technique uses a polyethylene sleeve smaller than the container which is stretched over the container and then closes around it.

20.6.4 Applying neck collars and tags

Both neck collars and tags present a simple addition to the pack and provide promotional opportunities. Neck collars are normally made using a thin paperboard with a hole cut out to allow the collar to fit over the neck. They can be automatically presented to the container and located onto the neck using a robotic pick-and-place machine. If the line speed is slow enough, they may be applied by hand. Tags are normally constructed using a fine cord, which may be elasticated, and which is attached to the tag. It is very difficult to apply tags automatically as the cord has to be passed over the neck of the container. Both neck collars and tags are, unfortunately, susceptible to damage in end-of-line operations and in the opening of the transit packaging. They are also susceptible to pilferage. One solution is to build a neck collar into a multilayer self-adhesive label and apply it from above using an adapted label application machine. Once situated over the neck the collar adheres to the container, making it more secure.

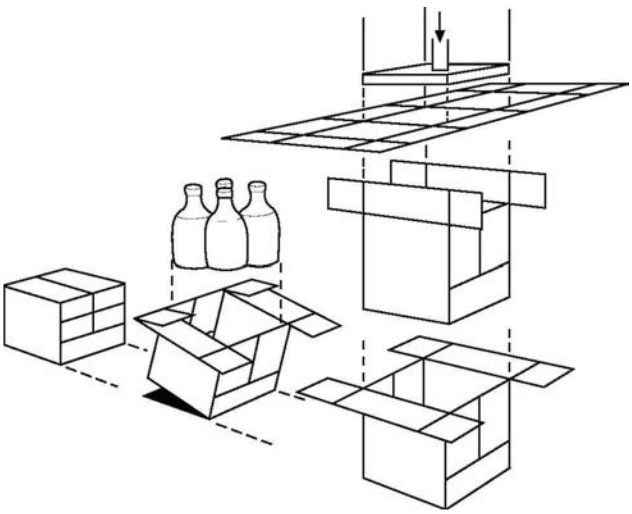
20.7 Cartonning

Cartons are used for a wide range of both solid and liquid products. See Chapter 10 for information on styles of cartons and grades of board used. Cartonning of liquids will be addressed later in the section on form, fill and seal machines. There are numerous different styles of cartons and cartonning systems and this section covers only the key principles.

Folding cartons are amongst the most common types used. They are delivered packed flat, usually with the side seam already glued, and placed in a magazine on the cartonning machine. Using suction caps, a carton is taken from the magazine and erected into its required shape. One end is then closed using adhesive, or by means of a tucked-in flap and the assembled carton is now ready for insertion of the product (which may have been sealed into a bag or sachet prior to this point, or may be unwrapped). Robust products can be dropped into the assembled carton from above, using gravity, whilst more fragile items (e.g. a decorated sponge cake) require more careful insertion by pushing in the horizontal direction. The carton is then fully closed, again using adhesive and/or an arrangement of tuck-in flaps and the filled cartons are moved to the next stage in the packaging line. An alternative is to use a flat, unglued carton blank, which is erected on the cartonning machine prior to filling and closing – see Fig. 20.19.

Sleeves are an alternative to cartons, and are also supplied folded flat and creased to allow automatic assembly. Both sleeves and cartons can be supplied unglued, in which case they are wrapped around the inner product and glued as part of the packaging line operation.

As mentioned, carton ends can be glued or tucked in place, the choice being decided by the degree of tamper evidence required and whether or not the carton is expected to be used more than once (a glued carton usually has to be torn to gain access to the contents). Another approach for one end is the 'crash-lock' design which uses



20.19 Erection, filling and closing of flat carton blank.

interlocking flaps and is easy and quick to assemble for filling, as well as being more robust than glued or tucked ends. However, this requires more complex folding and gluing at the carton production stage.

20.8 Form, fill and seal (FFS) packaging operations

Form, fill and seal (FFS) describes a packaging operation in which the 'container' is formed as part of the packaging line (rather than being made elsewhere, such as on a glass bottle forming machine) immediately prior to the product being filled into it, and then the filled container is closed, usually by heat sealing. The flexible packaging materials used are supplied in reel form and invariably include thermoplastics, often combined with paper, board and aluminium foil, according to the product's needs. FFS is used for a wide range of packs and products, including sachets for single portions of sauces, cartons of fruit juices and sacks for 25 kg of fertiliser and animal feed products.

The main types of FFS machine are:

- vertical (VFFS) machines, used for liquids such as fruit juices and soups, and solids such as frozen vegetables, sugar, crisps and wrapped sweets
- horizontal (HFFS) machines used for cakes, biscuits and bars of confectionery.

Variations on the above include:

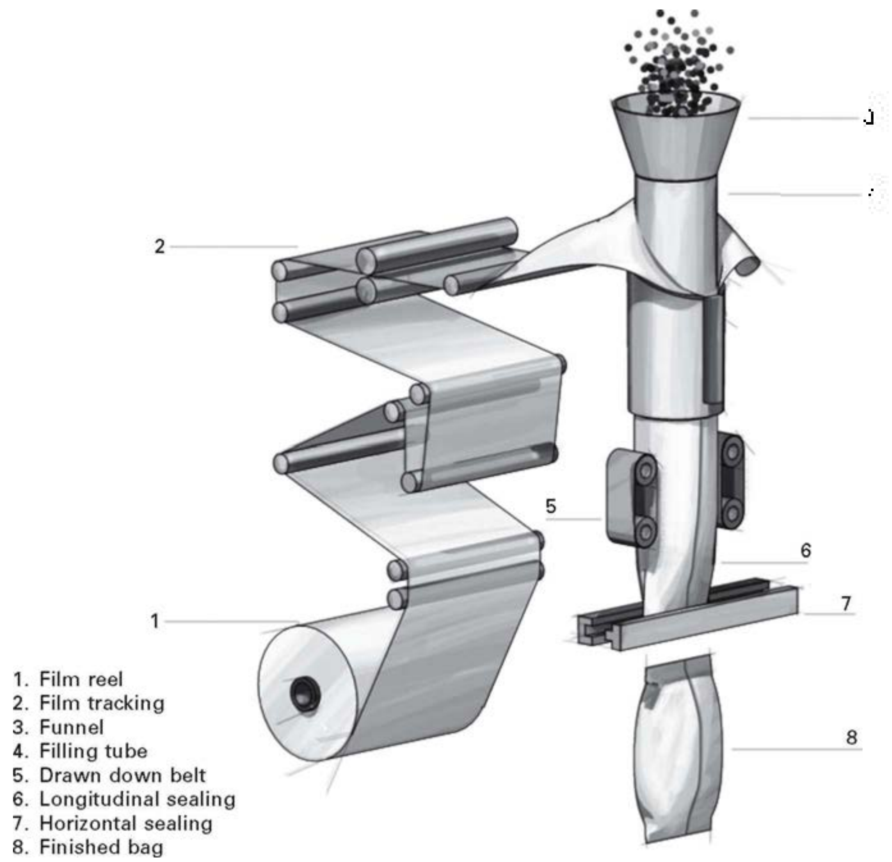
- sachet forming and filling machines used for dried soups, moist tissues and trial sizes of products such as shampoo
- thermoforming machines used for meat, cheese and yoghurt
- blister packing machines used for tablets.

20.8.1 Vertical FFS machines

The basic operating principles of VFFS machines are shown in Fig. 20.20. The film is unwound from a reel and drawn over a forming collar to create a bag shape. It is then wrapped around the vertical filling tube and sealed along what will become the length of the bag. The film is pulled down by the draw down belt and sealed at the bottom. The product is loaded through the tube into the bag. Horizontal jaws come up to seal the top of the bag and cut it away so that the filled bag can fall down the outfeed chute of the machine.

The finished pack can be a simple pillow shape as shown. Alternatively, it can be formed in an appropriately shaped forming box to give a rigid rectangular cross section with excellent 'stand up' properties (e.g. for liquids) or the sides can be gusseted to improve shelf and pallet stacking. Opening and reclosing features such as plastic zippers can also be incorporated. Rotating the sealing bars can be used to create tetrahedron shapes.

An alternative type of VFFS machine does not require a forming shoulder and has a continuous action (see Fig. 20.21). The machine feeds two webs of film or laminate to form a vertical channel, using heated and crimping rollers. A horizontal seam is

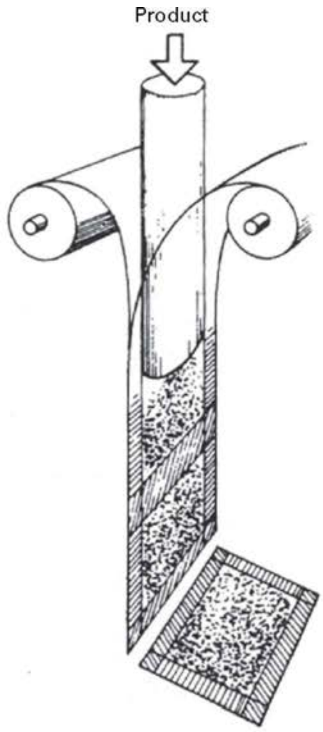


20.20 Basic operation of a vertical form, fill and seal machine.

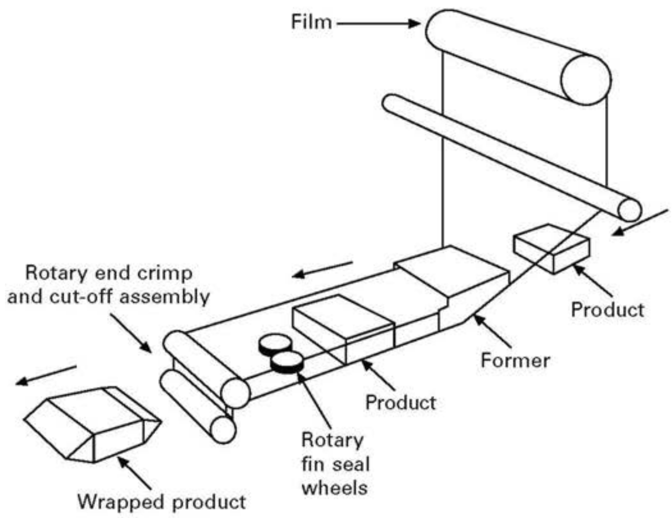
created to seal the base. Product is then filled into the newly-formed pouch and the top is sealed, at the same time forming the base of the next pouch. The strip can then be cut up into individual pouches. This type of machine is particularly suitable for filling liquids, and in some systems liquid flow is continuous, which means that the film or laminate must be suitable for sealing through the liquid product. Sealing and cutting of the pouches creates a pack with no trapped air, ideal for perishable foods and aseptic food processing.

20.8.2 Horizontal FFS machines

HFFS machines or ‘flow wrappers’ are used when the product is fragile and cannot withstand the drop down the filling chute of a vertical machine, e.g. bars of chocolate, cake bars and biscuits. The film is fed into a forming box where it is formed into the desired shape, continuously sealed along the sides and partially cut so that it starts to form an individual container (Fig. 20.22). At this point the product is fed into the container from a conveyor belt using push bars or ‘flights’ to separate and direct



20.21 Variation of VFFS operation.



20.22 Basic operation of a horizontal form, fill and seal machine.

each product into a single container. Each container is then sealed at both ends and then separated into individual packs.

Most flexible films or laminates used on VFFS or HFFS machines are heat sealed.

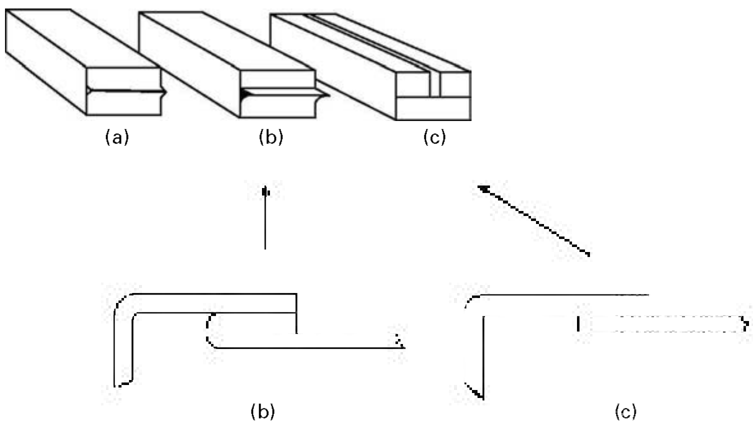
A heat sealer heats the surfaces and applies pressure to fuse them. The strength of the seal is determined by the temperature, pressure and time of sealing as well as the type and thickness of the two films or the heat-sealable coating. The seal is weak until cool and should not be subjected to stress during cooling. There is a range of different types of sealer: hot-bar or jaw sealers hold the two films between heated jaws until the seal is formed, whereas impulse sealers clamp the films between cold jaws which are then heated to create the seal. Impulse sealers can reduce wrinkling or shrinking of films during sealing. Rotary or band sealers are used for higher filling speeds, working by passing films between two heated belts followed by cooling belts which clamp the films together until the seal develops. Other types of sealer include high frequency sealers, in which an alternating electric field induces molecular vibration in the film which heats and seals it, and ultrasonic sealers which induce high frequency vibrations to heat and seal the film.

The development of cold seal adhesives, requiring only pressure to seal the film wrap, has removed the need to apply heat. This has the benefit of not adversely affecting a heat-sensitive product (e.g. chocolate or ice cream). It also allows the line to operate at much higher filling speeds. However, cold seals are not generally as strong as heat seals. This is an advantage in terms of pack opening, as it is relatively easy to pull the seal open.

There are three common styles of seal:

- bead seals
- fin seals
- overlap seals.

A bead seal (Fig. 20.23(a)) is a narrow weld joining the two edges of the film. A fin seal involves folding one edge of the film over before it is sealed to the adjoining edge, leaving a double layer of material as a 'fin' which is often folded back on itself, to lie flat (Fig. 20.23(b)). It uses more film than a bead or overlap seal but is suitable for film that is only sealable on one side (e.g. because it has a sealable coating on one side only). In an overlap seal the front and back surfaces of the film are lapped



20.23 Styles of seal: (a) bead; (b) fin; (c) lap.

one over the other, giving a flat seal (Fig. 20.23(c)). This is very economical on material, but requires the front and back surfaces to be sealable to each other.

20.8.3 Sachet forming and filling machines

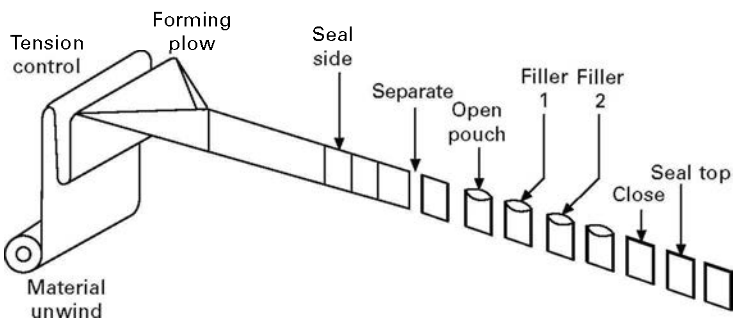
In this method of filling, the web is usually a printed laminate. It is unwound from the reel and folded in half along its length. Using the photoelectric cell registration marks on the web, the machine applies sealing and cutting bars at the appropriate locations, thus making open-ended pouches, which can then be filled with the product (Fig. 20.24). In the illustration shown there are two filling heads (1 and 2), one of which can be used to insert a folded towel and wad, and the second to dispense a liquid cleansing or sterilising agent. The filled sachets are then sealed at the top and moved to a collation station for further wrapping, e.g. using a film overwrap or cartonning.

20.8.4 Thermoforming packaging machines

Such machines usually operate on a horizontal bed. A base web is unwound and thermoformed into the required shape, e.g. rectangular cross section for stacks of sliced ham, circular cross section for pots to contain yoghurt. See Chapter 14 for information on thermoforming processes. Multiple packs can be formed across and along the length of the web. The product is dosed, by hand or machine, into the newly-made shapes and a top web applied to seal it in place. The finished packs are then cut out and the waste skeleton or matrix wound up and removed for disposal.

20.8.5 Blister packaging

Blister packaging is widely used for items such as tablets, which are contained in indentations or pockets in a plastic strip and sealed with a foil material. The base film which forms the strip is initially unwound and thermoformed to make the pockets. These are then filled with tablets using systems such as channel-feed (which can give a mix of different products on the same blister) or a relatively simple brush box (see previous section). After inspection (normally using video inspection techniques), a



20.24 Sachet forming and filling machine.

top web of aluminium foil or a laminate is placed over the strip and heat sealed onto the filled film. The batch code and other details are embossed into the blister, which is then cut out of the film. The waste skeleton is removed and the blister travels on, normally to a horizontal cartonning machine.

An alternative form of blister packaging is used, for example, for hardware items such as small tools and decorative handles (see Chapter 10). The item(s) to be packed are placed on a perforated board which has been coated with a heat-sensitive adhesive varnish. A thermoplastic film is heated and draped over the items and the board, and a vacuum is applied to pull the film onto the products, which heat bonds the film to the board.

The construction of blister packaging machines depends on how fast they are required to run, and how often they need to be reconfigured to accommodate a different product specification. Intermittent operation flat-bed machines have an operating speed around 30 cycles per minute. They are relatively simple which makes changes easier to undertake. Higher speeds and longer runs of the same shape of product require machines with wider widths of film and rotary forming stations, coupled with more sophisticated filling, inspection and cutting devices. These machines are more expensive to build and reconfigure. This has to be balanced against the increased output available.

In more sophisticated systems, FFS machines can also be combined with a blow moulding system to develop more complex three-dimensional shapes from a thermoplastic web. Another variation of the form-fill-seal process is the unit-dose bottle blow-fill seal machine. This incorporates an ingenious combination of extrusion-blow, filling and sealing techniques. The small containers are formed using the extrusion blow process, but the necks are shaped to a small funnel. The liquid product is then filled into the containers. The containers are then heat sealed to close the pack. The bottles may be supplied singly or in strips. They are then finish-packed on to display cards or placed in cartons as required.

20.9 Direct product shrink-wrapping and stretch-wrapping

Flexible films such as LDPE are designed to be stretched over and then shrink around an object, for example food placed in a pre-formed tray. A small amount of shrinkage may be required to tighten around a simple shape requiring loose wrapping (e.g. greetings cards) whilst higher shrinkage is required for more contoured packs requiring tighter wrapping, e.g. frozen turkeys, to exclude air.

The degree of shrinkage of flexible films is measured according to two types of ratio: degree of shrinkage across one axis known as the machine direction (MD) compared to shrinkage across the crosswise or transverse direction (TD). Films are categorised as one of:

- preferentially balanced, e.g. MD = 50%; TD = 20% (i.e. high shrinkage in one direction)
- fully balanced, e.g. MD = 50%; TD = 50% (high shrinkage in both directions)
- low balanced, e.g. MD = 10%; TD = 10% (low shrinkage in both directions).

These different characteristics play a major role in selecting film, measuring and cutting it to shape and the means to complete closure around the product.

There are two ways of closing the film around the product and its container:

- shrink-wrapping
- stretch-wrapping.

In the former, the film is wrapped loosely over the product, which may be placed in a plastic tray, or the product may be placed in a bag, e.g. poultry or joints of meat. It is then passed through a hot-air tunnel, beneath heaters or subjected to a pulse of hot air, or dipped into a hot water bath, the heat causing the film to shrink around the product. In stretch-wrapping, the film is wrapped around the product (e.g. cuts of meat on a tray) under tension. As the tension is released, the film secures the product to the tray. The main advantages of stretch-wrapping over shrink-wrapping are lower energy and film use. This kind of packaging is often combined with, and needs to be compatible with, modified atmosphere packaging systems.

20.10 Modified atmosphere packaging

As mentioned in Chapter 3, the purpose of modified atmosphere packaging (MAP) is to extend the shelf life of a product, typically fresh foods. It inhibits spoilage by replacing the air in a package with a mixture of gases. The gas mixture used is usually selected from oxygen, nitrogen and carbon dioxide. The mixture of gases displaces the air in the headspace above the product fill level. For fragile products such as prepared salad and savoury snacks, the pressure of the gases in the package also helps to protect the product from damage during transport. Another way of modifying the atmosphere is to remove as much of the air as possible, in which case the process is described as vacuum packaging.

MAP works by limiting the microbial activity and chemical processes which cause spoilage. Maintaining suitable atmospheric conditions within a package is complicated because fresh produce continues to 'breathe' or respire within the package, absorbing oxygen and producing CO_2. Accounting for respiration requires the use of a permeable film which allows a certain amount oxygen and CO_2 to move in and out of the package to maintain the balance of gases in the package. Films may also need to allow the moisture generated during respiration to escape so that it does not build up in the pack. Typical films used are coextruded films or laminates of HDPE, LDPE, EVOH, PP and PET. MAP operations also require maintaining a low microbiological count in the product to limit the potential for microbial spoilage.

In a typical batch MAP processing system, air is removed from preformed bags which are then flushed with the gas mixture (typically using a tube inserted into the bag) before the package is heat sealed. In continuous MAP systems, food is packaged either in semi-rigid thermoformed trays which are covered with film or alternatively in pillow pouches or flow packs using either vertical or horizontal form-fill-seal equipment. FFS and shrink-wrapping systems are particularly suitable for MAP. The process of shrinking the film around the product under heat helps to sterilise the packaging film, limit microbial contamination and remove the air to allow an appropriate gas mixture to be added to the product headspace as the film closes around the product and is sealed.

20.11 Miscellaneous wrappers

Twist wrapping machines are mainly confined to the traditional confectionery industry for the wrapping of individual sweets. The sweet or other item is automatically placed onto the edge of the wrapping material (normally a crease-retaining film such as Cellulose™). This is rolled around the sweet whilst holding the ends of the film so that they are twisted together. Bunch wrapping is also used for confectionery and for wrapping soaps. The product is placed in the centre of a square of material which is brought up around it to give the required effect. For soaps, a decorative label is often applied to the bunched area.

Roll wrappers are used for some confectionery products and are widely used for biscuits. The items are collated into the required number per pack and placed on the edge of an oblong sheet of wrapping material such as polypropylene film. This is rolled around the product stack, sealed along its length and the ends folded in and sealed either with glue or through a combination of heat and pressure to fuse the film, using either an overlap or fin seal.

20.12 Coding systems

In any packaging operation it is essential to be able to identify when a batch was made and packed, and even which machinery was used and who operated it. In the event of a problem with the safety or quality of a product, it is essential to be able to identify which batch it came from. It will then be possible to identify if other products from the same batch are similarly affected, the likely source of the problem and whether other batches might also be affected. If the problem is serious, it may be necessary to recall all of the possibly affected batches from the market. These requirements can be met by giving each batch a code which can be applied to the packaging of each item in the batch during the packaging operations. As well as a unique code, dates and times are sometimes added to identify precisely when an item was packed. In the case of perishable items, it may also be necessary to add 'best before' or 'use by' dates for the benefit of consumers during the packaging process either to the package or to the label.

The techniques available for batch coding include:

- embossing
- hot foil printing
- thermal transfer
- inkjet printing
- laser marking.

The process of embossing is essentially letter press printing, with or without the ink, but using steel type to press into the substrate material. Embossing can be done by setting the type into a roller and using this to imprint the flaps of a carton as they pass through the machine. Another example is in tablet blister packing where the type may be built into the heat seal station.

In hot foil printing the type is heated to approximately 130°C and pressed against a film which carries a coating. When the hot type presses the film against the packaging, the heat seals the coating onto the material leaving the mark of the typeface. This method was the established means of coding self-adhesive labels until thermal transfer printing was introduced. Thermal transfer printing uses a similar film to that used for hot foil coding, but the print image is generated by wiping a heater bar across it. Within the bar there is a row of tiny ceramic heaters which are switched on and off at the appropriate moments to create the required print effect.

Whilst hot foil and thermal transfer require the product to be stationary during the print process, inkjet printing relies upon the movement of the product along the belt to give the horizontal component of the print matrix. This requires some form of encoder to enable the machine to respond to variations in the speed of the belt. The inkjet head incorporates a set of individual jets which are switched on and off at the appropriate moments to print a dot of ink to build up the matrix. Others use the electrostatic deflection of a stream of ink particles (see Chapter 19).

Similar systems may be used with low power lasers which are cheaper to operate because no ink is required. These may work by 'ink ablation' in which the surface of the material is removed to leave a white mark out of a coloured background, or by reactive colour change in which an appropriate light reactive pigment is included within the material and changes colour when exposed to the intensity of the laser beam. Lasers may also work on the 'dot-matrix' principle as described for inkjet printing, or may work using the 'pulse-mask' principle, which is similar to a slide projector but uses stainless steel masks to create the required image. Laser systems can be used to etch codes onto suitable surfaces such as glass.

20.13 End-of-line equipment

The equipment required at the end of the line depends on the speed at which the line is running, the weight of the product and the form of secondary or transit packaging being used. This is usually:

- a shrink-wrap (possibly utilising some form of collation tray)
- a corrugated case (with or without internal fitments)
- a combination of both, such as shrink-wrapped point-of-sale units.

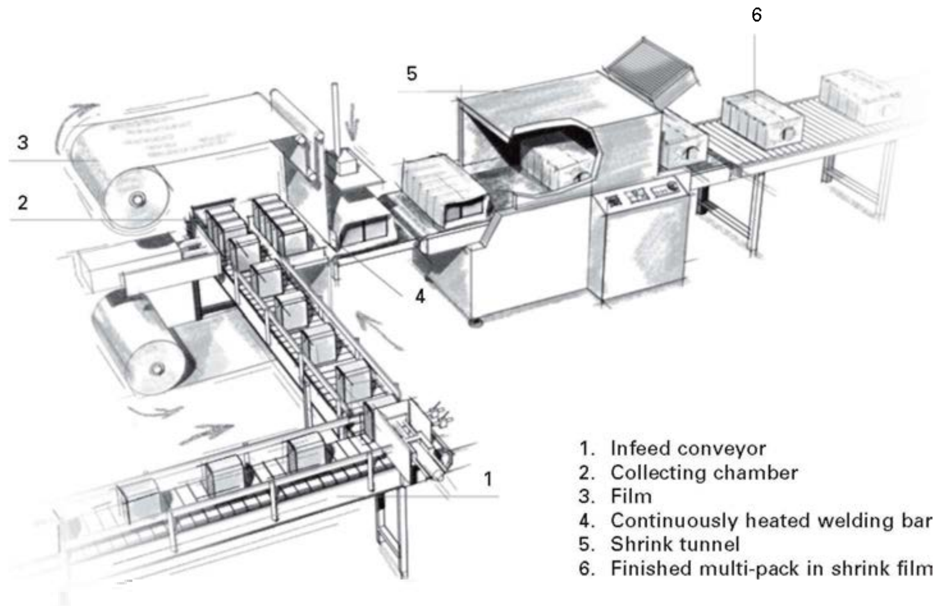
20.13.1 Secondary packaging: shrink-wrapping

The shrink-wrapping operation is influenced by pack design and operating speed. If a collation tray is required to hold the primary packs together for ease of handling, the appropriate mechanisms are required to handle those trays and load the product into them prior to wrapping with film. The design of the mechanism will depend on whether the trays have precise locations into which each of the packs has to be placed. If a simple flat-based tray is to be used, a simple mechanism to group the packs together and slide them into the tray will probably be sufficient. If specific locations are required then a more complex mechanism, such as a robotic pick-and-place machine, may be required.

A fully automated system for collating primary packs and presenting them for shrink-wrapping is shown in Fig. 20.25. Once the film is applied it must be shrunk in place. This is normally carried out in a heated tunnel. Care should be taken to avoid overheating both the film and the product. The selection of the correct grade of film for strength and shrink characteristics is essential for the effective operation of these processes, as well as control of dimensions such as film gauge and reel width. In some instances, after shrink-wrapping, products may be collated by the application of a band which is heat sealed to complete the wrap around the pack. Banding may also be used as a means of sealing cases.

20.13.2 Secondary packaging: corrugated cases

Corrugated cases are discussed in more detail in Chapter 11. Corrugated cases are usually delivered packed flat and, like folding cartons, can be glued for ease of making up on the packaging line, or left unglued for wrapping around a collation of primary packs. These operations may be carried out manually or automatically, depending on line speed. Automatic case erecting machines normally demand a higher level of dimensional accuracy from the cartons supplied than those which are manually assembled. This may mean that the cases need to be die cut to provide the required accuracy and consistency of dimensions together with features such as tapered slots and offset creases. Cases may be sealed using adhesive tape, or by cold wet glue



20.25 Shrink-wrapping of collated primary packs.

or hot-melt adhesives. It is normal to include a batch coding at the case sealing stage to enable product identification at subsequent stages in the warehousing and logistics chain.

20.13.3 Palletisation

It is normal to transport the secondary packs on pallets. The loading of the product onto the pallet may be manual, mechanically assisted or fully automatic, using robotic handling systems. Examples of mechanical assistance may include facilities such as:

- a roller conveyor to take the product as close to the pallet as practicable
- a vacuum-operated lift mechanism which uses a suction pad to lift the product and a swinging arm which operates like the jib of a crane to allow the operator to place the product onto the pallet without having to take its weight; the vacuum is then released so that the operator may direct the machine to pick up the next pack
- a moveable platform so that the pallet can be lifted and moved automatically to a designated storage slot.

An example of the latter is shown in Fig. 20.26. In a fully-automated pick-and-place robotic palletisation system:

- the layout of packs onto the pallet is programmed into a computer
- the computer controls the pick-up mechanism and the actuators
- the actuators control the movement of the pack
- the pack is lifted and placed in the next available location on the pallet.

If the packs are of a uniform shape, it is possible to use a mechanism which will:

- collate the packs into the required layout of the next pallet layer
- use a push-bar system to slide the whole layer onto the pallet
- re-position to the appropriate height for the next layer.

Palletised loads are normally stabilised using stretch-wrap film, which may be applied either manually or automatically. However, manual application requires the operator to hold a roll of film and walk around the pallet, bending up and down to guide the film to the required height, whilst pulling on the film to keep it tight. Clearly this is undesirable, both from a health and safety point of view, and in seeking to achieve a consistently effective wrap. Automatic machines normally work by placing the pallet onto a turntable and supplying the film through a mechanism which pre-stretches the film as it is applied to the pallet. The roll applicator mechanism moves up and down to apply the film to the required location on the filled pallet, as it is rotated by the turntable. Again, the selection of the correct grade of film for strength and stretch characteristics is essential.

20.26 Automatic palletisation.

20.13.4 Pallet labelling

The palletised load should be labelled to facilitate its identification and destination. This may be:

- a simple handwritten slip of paper tucked into the stack (not ideal)
- a pre-printed label which is applied to the pallet, either manually or automatically
- a label onto which the product details are printed by the application machine (probably using either inkjet or thermal transfer methods, and possibly incorporating the information into a bar code symbol) and then applied automatically to the required location on the pallet.

The location and number of pallet labels depend upon requirements of later stages in the supply chain. A label may need to be visible on each face of the pallet, either by applying four identical labels, or by repeating the information on labels which are applied around diagonally opposite corners of the pallet.

20.14 Quality and efficiency aspects of packaging operations

There is a range of automatic techniques available to ensure that the correct materials are being packed, and that the product is being assembled correctly. Sensors include those using light, electromagnetic waves, infrared radiation, microwave or radio frequency waves, gamma rays or ultrasound. A summary of types of sensor which may be used to monitor aspects of filling and packing sensitive items such as food and beverage products is shown in Table 20.1.

An example of these inspection systems is video tracking of the components and video inspection of the lot coding process. A widely used technique uses a simplified version of bar codes which can be read at speed. These may be applied, for instance at the fold and glue stage of the carton-making process, to ensure that different prints on the same cutting profile do not become mixed in the same job. They may also be used along a filling line to ensure that the correct components are being assembled. To take this to a further stage, optical detectors may be used to ensure, for example, that a promotional item (e.g. a leaflet) is not only dispensed but is actually placed within the carton. These techniques require adequate control procedures to ensure that they operate effectively.

20.14.1 Storage of materials

The storage of packaging materials is important both to ensure they are safe to use (e.g. clean and contamination free) and that they are fit for purpose. As an example, creases in cartons or corrugated cases delivered flat for folding into their final shape will become ineffective if storage times are excessively long and are cold and damp. The items will be difficult to make up, resulting in high wastage on the packaging line. Such materials should ideally be stored in the following conditions:

- ~20°C, 45–55% relative humidity (RH)
- no double stacking of pallets (which might put too much weight on materials at the bottom and could constitute a health and safety hazard)
- away from direct sunlight or cool air.

Other examples of packaging materials which may be adversely affected on the packaging line, due to poor storage are:

- Self-adhesive labels: adhesive failure may occur, or adhesive bleed around the die-cut edges of the label, which can cause labels to adhere to the underside of the carrier web.
- Glass bottles: labelling problems will occur if the bottles are brought into a warm, moist environment whilst still cold enough (from the warehouse) to cause condensation to form on the glass surface.

For maximum performance, all packaging materials, and especially those based on cellulose, are best used after they have acclimatised to the temperature of the packaging line environment, a practice known as 'conditioning'. Sudden changes

Table 20.1 Examples of measured parameters and types of sensors used in food processes

Parameter	Sensor/instrument type	Examples of applications
Bulk density	Radiowave detector	Granules, powders
Caffeine	Near infrared detector	Coffee processing
Colour	Ultraviolet, visible, near infrared light detector	Colour sorting, optical imaging to identify foods or measure dimensions
Conductivity	Capacitance gauge	Cleaning solution strength
Counting food packs	Ultrasound, visible light	Most applications
Density	Mechanical resonance dipstick, gamma-rays	Solid or liquid foods
Dispersed droplets or bubbles	Ultrasound	Foams
Fat, protein, carbohydrate content	Near infrared, microwave detectors	Wide variety of foods
Fill level	Ultrasound, mechanical resonance, capacitance	Most processes
Flowrate (mass or volumetric)	Mechanical or electromagnetic flowmeters, magnetic vortex meter, turbine, meter, ultrasound	Most processes
Foreign body detection	X-rays, imaging techniques, electromagnetic induction (for metal objects)	Most processes
Headspace volatiles	Near infrared detector	Canning, MAP
Humidity	Hygrometer, capacitance	Drying, freezing, chill storage
Interface – foam/liquid	Ultrasound	Foams
Level	Capacitance, nucleonic, mechanical float, vibronic, strain gauge, conductivity switch, static pressure, ultrasound	Automatic filling of tanks and process vessels
Packaging film thickness	Near infared detector	Packaging, laminates
Particle size/shape distribution	Radiowave detector	Dehydration
pH	Electrometric	Most liquid applications
Powder flow	Acoustic emission monitoring	Dehydration, blending
Pressure or vacuum	Bourdon gauge, strain gauge, diaphragm sensor	Evaporation, extrusion, canning
Pump/motor speed	Tachometer	Most processes
Refractometric solids	Refractometer	Sugar processing, preserves
Salt content	Radiowave detector	Pickle brines
Solid/liquid ratio	Nuclear magnetic resonance (NMR)	In development
Solute content	Ultrasound, electrical conductivity	Liquid processing, cleaning solutions
Specific micro-organisms	Immunosensors	Pathogens in high-risk foods
Specific sugars, alcohols, amines	Biosensors	Spoilage of high-risk foods

Table 20.1 Continued

Parameter	Sensor/instrument type	Examples of applications
Specific toxins	Immunosensors	High-risk foods
Suspended solids	Ultrasound	Wastewater streams
Temperature	Thermocouples, resistance thermometers, near infrared detector (remote sensing and thermal imaging), fibre-optic sensor	Most heat processes and refrigeration
Turbidity	Absorption meter	Fermentations
Valve position	Proximity switch	Most processes
Viscosity	Mechanical resonance dipstick	Dairy products, blending
Water content	Near infrared detector, microwaves (for powders), radiowaves, NMR	Baking, drying, etc.
Water quality	Electrical conductivity	Beverage manufacture
Weight	Strain gauge	Weighing tank contents, checkweighing

of temperature and humidity should always be avoided, e.g. taking cartons from a cold warehouse or, worse still, from a cold delivery vehicle onto an automated packaging line will almost certainly result in poor performance. The technical ideal would be to have controlled atmospheric conditions in warehouses but this is likely to be economically prohibitive. The alternative is to aim for minimal storage time of packaging materials (by having close stock controls and just-in-time deliveries) and to hold the materials in a conditioning area for 48 hours prior to use.

20.14.2 Maintenance and training

The correct setting up, operation and adequate maintenance of the packaging line equipment is essential to ensure that product of the correct quality is produced as economically as possible. Thorough training of line technicians and machine operators is required to ensure that machines are operated as efficiently and safely as possible (for both the operators and the machines). Health and safety regulations and the ISO 9001 quality standard both require that accurate records are kept and reviewed to ensure that the staff and equipment are capable of the processes required of them to manufacture the product. It is good practice to have clear, written operating and maintenance procedures as well as records of what training staff have undertaken and what maintenance has been done.

20.14.3 Calculating line efficiency

Line efficiency is defined and calculated in different ways by different companies, and this section is not intended to debate the pros and cons of the various methods used. It is, however, important to try to be clear at the outset about what is being measured. Some key terms and their common definitions are defined below.

- *Station*: the term commonly used to describe each machine serving a specific function in the packaging line.
- *Running speed*: the time taken for a station to complete its cycle (e.g. for a filling machine to fill one container), sometimes defined as the number of cycles the station can complete in a given time.
- *Design cycle rate*: the speed of a station running empty (set by the machine manufacturer after testing).
- *Design speed*: the theoretical running speed of a station under perfect operating conditions (slower than the design cycle rate). This is often defined as the number of containers the station can process in a minute (cpm).
- *Input*: the numbers or volume of product (e.g. the number of containers to be filled) entering the station at a given point in time.
- *Output*: the quantity of product leaving the station at a given point in time under realistic operating conditions.
- *Efficiency*: usually defined as a ratio of output over input.

It is important to understand that the design cycle rate or design speed are not the same as output or efficiency. The latter are (or should be) calculated based on real operating conditions over time as experienced by other manufacturers using the equipment. No machine runs continuously at its design speed. A machine may be marketed with a design speed of 50 cpm which means that, in theory it should process 3,000 containers each hour. In practice, however, it may be affected by common operating problems such as variations in power supply, variability in supply or quality of product, containers or other packaging materials required to complete its operations, blockages, component problems, the need for maintenance and cleaning as well as wear. This may reduce average output in real operating conditions to, for example, 2,500 containers each hour (41 cpm) or 83% efficiency.

In working out the specification required for a machine, it is best to start from the required output, select a machine with a higher design speed specification and look for reliable output data which will match the output required. Reputable machinery suppliers will have this data based on customer experience. It is always advisable to speak to other users. It is important to check potential differences in other users' operations such as the product being processed, levels of maintenance and operator training to assess whether data is comparable.

In setting a required output, it is essential to bear in mind the output of each station in the packaging line since the overall output can never be greater than that of the slowest station. Furthermore, variations in station efficiency have a cumulative effect on overall line efficiency, as the following example shows:

Unscrambler	→	Filler	→	Sealing machine
Design speed: 150 cpm		Design speed: 100 cpm		Design speed: 125 cpm
Efficiency: 95%		Efficiency: 90%		Efficiency: 98%

In this case the line cannot theoretically run any faster than 100 cpm, the filler's design speed. However, its output is 90 cpm (90% efficiency). The overall efficiency of the entire line would be:

$$100 \text{ cpm} \times 90\% \text{ efficiency (filling)} \times 95\% \text{ efficiency (unscrambling)}$$
$$\times\ 98\% \text{ efficiency (sealing)} = 84 \text{ cpm}$$

In this example, the output of the entire line would be 84% of the maximum theoretical design speed of the line. As a further example:

- a station with a design speed of 100 cpm might run at 95% efficiency (i.e. an output of 95 cpm or packs per minute)
- coupled with a second station also at 95% efficiency, this becomes 90 packs per minute coming out of the second station
- coupled with a third machine running at 95% efficiency, overall efficiency becomes 85 packs per minute.

By the time there are six machines in the line, overall output has been reduced to 73 packs per minute, i.e. overall line efficiency has been reduced by over a quarter from the theoretical design speed of the entire line.

20.14.4 Ways of optimising line efficiency

There are various ways of optimising line efficiency. As a rule, the most critical station in the packaging line is taken as the benchmark. This is usually the filling operation which is often the most complex operation and usually critical to product quality and safety. All other stations are, if possible, specified to run at a higher design speed so that they will always be able to match the output of the filler. Post-filling operations in particular are often designed with a higher design speed. Modern control systems then use this extra capacity to regulate the speed of stations to ensure a smooth movement of packaging to and filled packs from the filler. They also include stop/start controls to close down a station if a serious problem occurs.

In practice, of course, individual stations do not all operate continuously at the same level of efficiency and may vary in performance at different times, creating potential bottlenecks. One engineering answer to this problem is to have accumulating devices between each machine which store up product. Accumulators effectively isolate parts of the line from each other to allow production to continue. This means that, if one of the machines slows down, the machines feeding it may continue feeding the product into the accumulator. At the other end, subsequent operations can also continue by using up the accumulated stock produced by the problem machine. When the problem machine recovers, it also has a stock of accumulated product to process. It is possible to assess the size of accumulators by estimating the likely duration of any interruptions in supply. If it typically takes one minute to resolve most common production problems in a filler with an output of 90 cpm, a following accumulator would need to hold around 90 containers to ensure a continued supply of containers to the following machine. At low line speeds it may even be possible to remove the product from the line into temporary containers and feed it back on again when the line returns to full capacity. It is important to note that, whilst an integral element in many packaging lines, accumulators should not be a substitute for maximising the efficiency of individual machines and the packaging line as a whole.

A typical response to a problem with a particular station is to slow the line down until the problem is resolved and then increase the speed in stages back up to the desired level. It is important to strike the right balance between overall line speed and efficiency. As a general rule, the faster a machine is, the less able it is to cope with variations in inputs such as product and packaging materials and the more vulnerable to problems which reduce efficiency or product quality or which cause stoppages. It may be better to have a slower machine with higher efficiency, better output and more consistent product quality than a fast machine operating at a low level of efficiency.

It is also important to strike the right balance between standardisation and flexibility in optimising production. In general terms, the more dedicated a machine is to process a particular product and container type, the more efficient and reliable it is likely to be. There are often pressures to create innovative types of product and packaging format, or to have a broad range of product offerings (e.g. in differing sizes or weights), as a way of establishing a distinctive position in the market. It is unlikely that a single existing packaging machine will be sufficiently versatile to encompass all these needs. In these circumstances, it is essential for a business to factor in the capital costs of commissioning and acquiring new machinery as well as the operating costs of running a more complex packaging line or lines with potential delays for changeovers (see below). It may be better for overall product quality and cost to consider adapting existing packaging formats, for example, and settling on a small number of standard sizes which can be more easily handled by modifying existing technology with fewer changeovers.

20.14.5 Changeovers

Many packaging lines are designed to accommodate some variations in product, for example by filling different sizes of containers with the appropriate volume or weight of product. Some sort of changeover is then required. In general, machines using a cup or other container to measure by volume have a relatively fixed range compared to weighing machines or machines using metering devices (e.g. pumps) which can accommodate a wider range of variations. As a general rule, the faster a machine, the more complex the changeover is likely to be.

Where frequent changeovers are required, the ease and speed with which each changeover can be achieved may be more important than machine speed. A fast machine with complex, time-consuming changeovers may be much less efficient overall than a much slower, more easily adjusted machine. Ideally, changeovers should involve simple recalibration procedures (e.g. programming instructions for new weights) or simple component changes. It is important to factor in the higher staff costs involved in managing even relatively simple changeovers.

To avoid high inventory costs, many industries operate just-in-time (JIT) manufacturing systems which require maintaining continuity of supply if the rest of the supply chain is not to be compromised. Rapid changeovers may be critical in these circumstances. High volume production of standardised product will drive down unit costs but potentially increase inventory costs. On the other hand, frequent changeovers will increase unit costs for each run but keep inventory costs down. There is a point for an individual business at which each cost is minimised, commonly known as the economic order quantity (EOQ) (Fig. 20.27).

A changeover can be divided into several stages:

- *Preparation*: having appropriate procedures, components and tools together with properly trained staff familiar with the technology and the steps involved
- *Changeover*: replacing components; recalibrating machines
- *Trial run*: testing, final adjustments and run-in time, i.e. the time to bring the machine and packaging line back up to full speed.

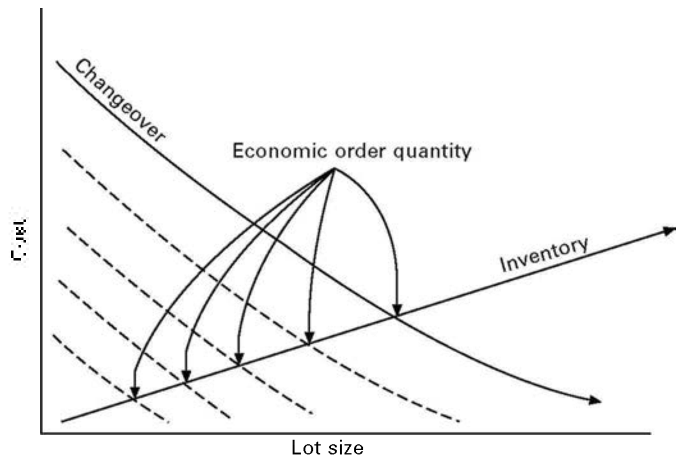
Changeover times can be improved by measuring what actions take up most time in practice and ways in which these actions can be made more efficient, for example by:

- improving procedures (e.g. by simplifying and standardising steps and, where possible, having precise, quantified settings to follow)
- improving the quality of documentation (e.g. by breaking down the process into a series of simple, easy-to-follow procedures)
- improving training
- managing as much of the changeover as possible off-line
- using as few components and tools as possible to effect changes
- performing changeovers from one access point.

20.14.6 Using existing or new machinery to increase production

There are several options for increasing production:

- use a third party, e.g. a contract packer



20.27 Economic order quantity.

- increase the efficiency of the existing equipment
- expand production with additional or larger machines (either new or refurbished).

A contract packer is a specialist company offering additional packing services to businesses. Temporary fluctuations in demand may best be met by using reputable contract packers rather than investing in expanding existing capacity which may then be unused when demand returns to normal. Contract packers can also be used in the short term if there is a more sustained increase in demand whilst a business is building up additional capacity, or if a new product line is required which may take a business time to plan and implement. If a contract packer is used, it is important to use one familiar with the product and able to meet the packaging specification, quality, legal and delivery requirements of the customer. These requirements will differ significantly for products such as nuts and bolts vs. food/pharmaceuticals.

Adapting, increasing the capacity or improving the efficiency of existing machinery to accommodate new lines or to increase production has obvious advantages over purchasing additional machinery. The technology is proven and familiar, capital costs will be lower, development time is shorter and less training will be needed. It may also be possible to add extra capacity by buying second-hand machines at reduced cost from companies specialising in selling reconditioned technology. However, these companies may not specialise in a particular product area and may have a limited understanding both of the specific requirements of a customer and of the detailed characteristics and history of a particular machine. Using existing technology will involve higher maintenance costs and may result in reduced efficiency due to wear and increased down time. Adapting an existing packaging line can also become counter-productive if the adaptations push it too far beyond its original specification. Older machinery may be incapable of dealing with new products or types of packaging, and may not be able to achieve increased quality standards in the market. A point may come when it is advisable to plan for a redesign of the packaging line using new machinery, particularly if a substantial new pack design or product line is agreed or a significant and sustained increase in production is anticipated.

20.14.7 Specifying and purchasing of new packaging machinery

Most packaging machines are built within a standard framework or configuration based around a standard pack format. Within this framework, they can then be customised in a number of ways:

- to process a range of sizes of pack
- to achieve a certain range of weights or volumes of product
- to include extra functions such as date coding, leaflet insertion, etc.
- to be compatible with other packaging machinery in the packaging line.

If a manufacturer wishes to avoid the risk and cost often associated with designing a completely new type of packaging machine, it is best to base any new design on a modification of an existing format that could be accommodated by adapting existing technology.

It is normal to begin the purchasing process by drawing up a detailed specification of what is required, possibly by discussion with suppliers. The specification should cover:

- product type, characteristics and requirements (e.g. liquid or solid)
- product processing requirements (e.g. temperature ranges machinery will need to operate in)
- packaging and sealing materials and requirements
- labelling materials and requirements
- basic pack shape and dimensions (including stability – simple shapes such as cylinders are easier to handle – and dimensions such as neck size)
- range of pack weights or volumes (and degree of accuracy) required
- number, type and speed of changeovers required
- output required
- ancillary items required (e.g. promotional leaflets)
- legal requirements (i.e. legislation applicable to the machinery and the product)
- hygiene requirements (e.g. for aseptic processing of food products)
- level of compatibility with other machinery in the packaging line
- potential hazards
- power and installation requirements
- maintenance, staff and training requirements.

Formal quotations are then sought. Other considerations include:

- the capital investment (a line could cost in excess of a million pounds)
- the quality and availability of support (e.g. access to spares and service engineers, quality of documentation and training for in-house staff)
- the timescale for design, construction installation and commissioning
- the operation validation requirements.

Some companies offer a 'turn-key' project management service. It is important to ensure that the requirements and scope of the service are clearly specified.

Once the contract has been agreed, the processes of design and construction may commence. These lead to the manufacturing site acceptance trials, which would include a full validation of all the operational requirements of the machine. The final stage is delivery, installation and commissioning, at which the performance of the machine is assessed to ensure that the required operational performance has been achieved.

20.14.8 Installing new packaging machinery

A packaging line consists of a series of linked machines with separate functions. Typically each will have come from a different supplier and will have its own requirements. To understand how each machine fits into the whole, the line has to be split into a series of clearly logical steps. This requires an understanding of the implications of making a change at any one stage. For example, the addition of an induction heat seal wad into a cap, with the associated equipment required, would call for close control of the torque applied by the capping machine, and of the speed of the belt through the induction tunnel. Failure to control either of these aspects would cause variations in the effectiveness of the induction field applied to seal the membrane across the opening of the container.

In planning the lay-out of a packaging line, it is important to leave sufficient space around the equipment for the delivery of bulk product (and how this feeds the filling machine) and components, through to the removal of the finished stock. It is also necessary to allow space for access by the line team to operate the machines, and to make it possible to clean and maintain the entire line, which may mean removing machines for an upgrade or major repair.

Health and safety of personnel is always of paramount importance in a packaging line. Moving parts must be adequately guarded and factors such as the total weight of material being handled by people must be considered to avoid repetitive strain injury. Professional advice must always be sought here. Of equal importance, packaging lines for products which are to be consumed must be designed and operated to an appropriate level of hygiene, such that the quality, safety and legislative requirements of the finished packed product are not compromised.

A general requirement is that the machine has been fully validated for the product it is to handle, and the materials it is to use. Not only is this in the interests of both health and safety, and of the economical use of resources, but it also has legal implications under material minimisation requirements of the EU Packaging Directive. If the filling line operation is being used as one of the criteria restricting further minimisation, it is necessary to have undertaken trials to confirm that the process may not be operated effectively using less substantial grades of packaging materials. This is addressed further in Chapter 4. In addition to the consideration of the material/machinery interface and implications for the selection of appropriate packaging materials indicated within this chapter, reference must also be made to the chapters relating to those particular materials.

Installing new machinery or packaging lines requires consideration of the services required to operate machinery, including power sources such as:

- electricity
- steam
- compressed air.

It also requires allowing for:

- ventilation
- means for the provision of packaging to the line
- the removal of any wrappings used to supply the packaging (e.g. film wraps and core bungs used on reeled materials, or corrugated cases used for supplying folded cartons)
- the removal of finished product and its secure storage.

Accommodation will also be required for:

- the line staff, who will require to change into appropriate work clothing, and may also be required to have washing and changing facilities
- the supporting engineering services require stores for equipment and change parts
- facilities for the cleaning of machines, especially the parts in contact with the bulk product, and equipment for the cleaning of the production facility
- the space needed to carry out quality inspection processes and store any inspection equipment
- the warehousing and materials handling facilities
- if the line is not being installed solely as a production unit, there would also be the need to provide accommodation for the other aspects of the company.

20.15 Problem-solving on the packaging line

There are several factors which may contribute towards problems on a packaging line, including:

- the design and specification of the machines (which may have been modified from their original design to handle this product)
- the setting adjustment of the machines
- the specification of the packaging components
- the condition of the packaging components (as indicated earlier these may be adversely affected by their storage)
- the adequacy of training given to the line personnel
- the standards of quality of output required.

Consequently it is necessary to take a careful methodical approach to establish the contributory factors, in order to determine what steps would be appropriate to deal with the problems. This is a science in itself, known as operational research. Thankfully, the development of computerised controls on the machines has made the diagnostics of machine operation easier. However, it will not help if there is an issue with the quality of the packaging components. These need to be carefully assessed as the source of the problem may not lie with the supplier.

As an example, a problem of the backing paper of self-adhesive labels snapping in the application machine may be caused by:

- incorrect manufacture of the face material of the label
- incomplete coverage of the silicone coating of the backing paper
- damage to the backing paper at the die-cutting stage of the label printing
- damage to the labels such as inadequate slitting of the rolls or failure of splices introduced during re-wind/inspection of the labels
- poor storage conditions leading to damp labels
- careless handling of rolls of self-adhesive labels may damage the edges of the backing paper and cause tiny cuts to occur which spread under tension
- damage by a hot-foil coder unit which is incorrectly set and creates cuts in the backing paper
- sharp edges in the machine which may damage the backing paper

- an engineering fault within the mechanism of the capstan causing it not to pull evenly
- a worn dispensing beak which is no longer straight, thereby causing uneven tension within the backing paper
- or a combination of some of the above.

Each of these possible causes has further tests that may be undertaken to identify the sources of the problem. As some causes go beyond the packaging components, it is important that the investigation is done in collaboration with the other members of the production team.

20.16 Sources of further information and advice

Details of packaging equipment may be obtained from specific suppliers, which are too numerous to list here. Contact may be made via the appropriate trade magazines and exhibitions, or the Process and Packaging Machinery Association (www.ppma.co.uk).

Other sources of information include: British Contract Manufacturers and Packers Association (www.bcmpa.org.uk) and the Packaging Machinery Manufacturers Institute (www.pmmi.org).

Reference should also be made to the BRC/IOP Global Standard for Packaging and Packaging Materials, Issue 4, London, TSO.

21
Hazard and risk management in packaging

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Abstract: This chapter deals with hazard and risk management (HARM), as it applies to the packaging industry. The chapter describes the use of specific methodologies for the development of effective HARM systems. Industry technical standards and associated certification schemes which also have a part to play are reviewed.

Key words: hazard and risk management (HARM), hazard analysis critical control point (HACCP), prerequisites, packaging industry standards.

21.1 Introduction

Hazard and risk management (HARM), as it applies to the packaging industry, has emerged in recent years as a result of two main drivers: cost control and avoidance of litigation, which are to some extent linked. It is possible to see the evolution of HARM as starting from 'failure mode effects analysis' (FMEA) (Beauregard *et al.*, 2008) and hazard analysis critical control point (HACCP) (United Nations Food and Agriculture Organisation, 2003). Each of these techniques was based on a preventative approach to the assurance of reliable and safe products, mechanical and food, respectively.

More recently the term 'risk management' has come into use, describing an approach to providing a means of protecting companies, their stakeholders and their brands from changes, events or incidents with the potential to cause damage (Kaye, 2008; Smith and Politowski, 2008). One reason why risk management has increased in importance is recognition that many business operations have greater dependence on third parties. This is a consequence of a trend towards outsourcing of components (or complete products) as well as services such as design, development, marketing and distribution. Control of risks associated with remote, supplier-dependent aspects of a business has become an inherent part of normal operating arrangements for many companies.

A reliance on suppliers and service providers characterises most of the packaging industry. Not only does the manufacture of packaging have its own, often extended, supply chain, but its products are destined to be part of a complex and demanding chain of supply for virtually every manufactured product, and a wide range of agricultural produce, as well as raw materials. Many of the raw materials used in packaging manufacture are sourced globally. These included paper, carton board, polymers and coating chemicals, each of which may be used in contact with hygiene-sensitive products such as food. This is why, in some circumstances, HARM may be applied backwards in the supply chain, as well as forwards. Industry technical standards and associated certification schemes also have a part to play. This is dealt with in Section 21.5.

Such is the diversity of packaging types and uses that the application of HARM is generally specific to each circumstance. This is why hazard and risk analysis is a vital tool for packaging professionals. Whilst it has a wide application across all of commerce, it is mainly industry sectors with links to the consumer that have applied HARM. There are several reasons why this is so. Major among these has been the perceived need amongst UK retailers to protect their brand value from damage. In the UK in particular, concerns over threats to the consumer from foodstuffs have had a very high profile from time to time. Each of the above influences has played a part in raising the importance of HARM as a management technique. There have also been social and societal changes resulting from increasing prosperity and the expectations and aspirations that follow. Caution is a phenomenon that thrives on affluence.

The terms 'hazard' and 'risk' are themselves problematical. In some languages they have the same or very similar meaning. It is essential to clarify this so that a consistent use of these words, with a common understanding of meaning, is achieved. For the purpose of this text the preferred meanings are as follows.

- 'Hazard' is the *potential* to cause harm/damage. Note that actual cases of harm need not have occurred for the potential to be recognised. Hazards are normally judged in terms of *severity*. This can be seen simply as estimating how dangerous an entity or event might be.
- 'Risk' is the *probability* that a given hazard will occur. The term 'risk' is often used interchangeably with hazard; for example commercial risk management as discussed above has to deal with hazards as well as risks. Risks are normally assessed in terms of *likelihood*.

Arriving at a rational position in these matters requires that hazard and risk are recognised as being different and must be dealt with as distinct phenomena that are nonetheless linked in any given case. The practical implications of this are dealt with in Section 21.4.

21.2 Packaging life-cycles in the supply chain

21.2.1 Background

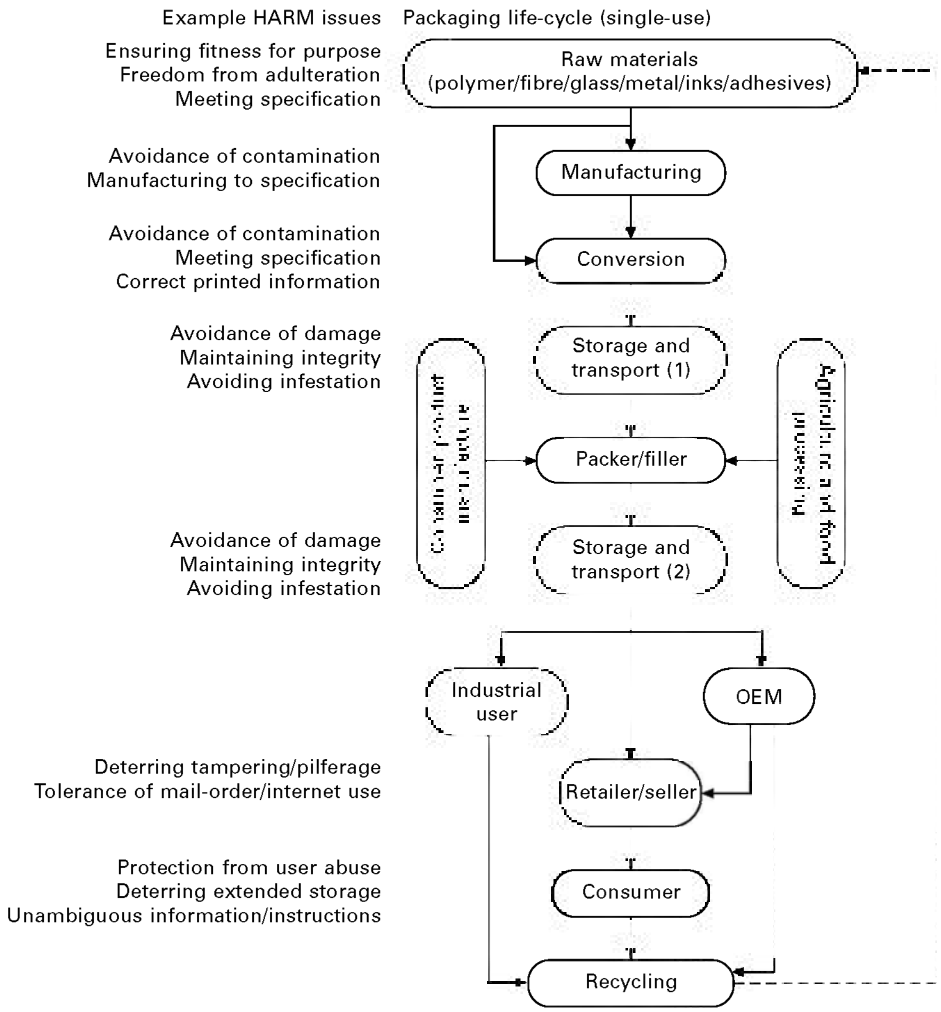
Present-day developed countries, with high urban population densities, rely on complex systems for the distribution of consumer goods and food. The balance between supply and demand can be delicate. For food, an extension of shelf life greatly reduces the fragility of supply management. This is where packaging can offer one of its important contributions. Foods with extended shelf life are almost invariably given this characteristic by a combination of processing, packaging and, in some cases, temperature control. Many perishable foodstuffs can also have greater longevity where appropriate protection is provided, normally by packaging.

It follows that the performance and sustained integrity of packaging are vital to food safety. Similarly, high-value consumer goods must complete the journey to the consumer in good condition. Two categories of packaging are employed in containment, storage and distribution. These are single-use (one trip), and returnable (often referred to as returnable transit packaging or RTP). They have different characteristics and functions, summarised in Table 21.1.

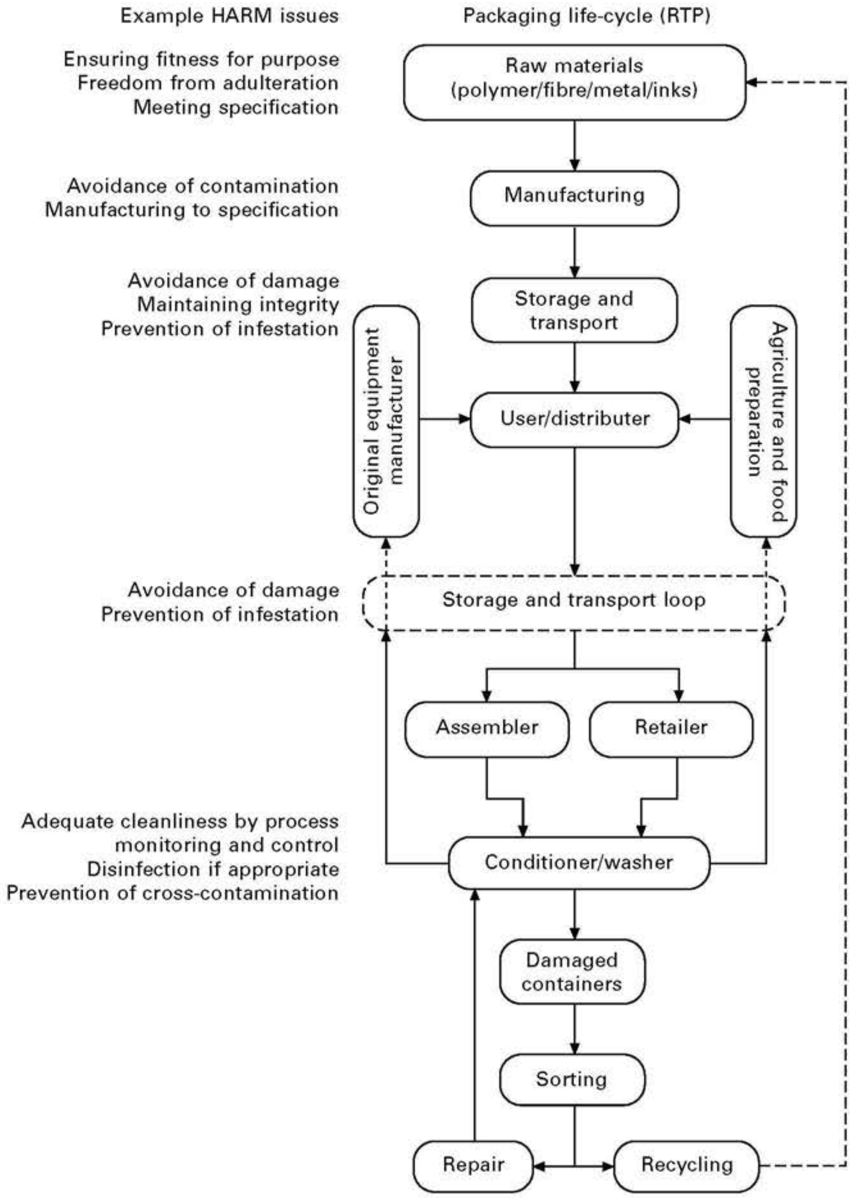
The life-cycles of these packaging types are illustrated in Figs 21.1 and 21.2. At each stage of manufacture, distribution and use, a range of differing hazards to the

Table 21.1 Comparison of single-use and returnable packaging

Single-use packaging	Returnable transit packaging
Often decorated for consumer appeal	Generally functional in design
Wide range of base materials used	Mainly plastics or corrugated board
Constructed for one trip only	Multi-trip capability
Re-cycling can be problematical	Long life and typically recyclable
May be crucial to food safety	Unlikely to compromise food safety



21.1 Example HARM issues in the life-cycle of single-use packaging.



21.2 Example HARM issues in the life-cycle of RTP.

packaging and its contents may apply. Examples that illustrate this are shown in the figures. These examples are not exhaustive but are intended to provide an indication of issues that need to be considered. The use to which packaging is put determines the design, materials and the hazards and risks it will be exposed to. It is not possible to list every combination of packaging type, product packaged, life-cycle challenge and end-use in this chapter. Table 21.2 list examples for a selection of packaging types, uses, associated hazards and possible consequences.

Table 21.2 Packaging types, example uses, hazards and consequences

Type	Use	Hazards	Example consequence(s)
Flexible polymer	Frozen food	Puncture	Contamination, freezer burn
		Seal failure	As above + product loss
	Mail order outer	Rupture	Damage to or loss of contents
		Abrasion	Weakening, loss of print/decoration
Rigid polymer	Consumer products	Weld or adhesive failure	Product damage or loss, pilferage
		Fracture	As above + fragment release
	Food and drink	As above	Product leakage and/or microbiological compromise or physical contamination
Carton board	Consumer products	Physical deformations	Loss of shelf appeal Package/product tampering
	Food	Adhesive failure	Product loss or contamination
Glass	Bottles and jars	Broken glass fragments	Consumer distress; high likelihood of claim and adverse publicity
		Closure seal failure	Product leakage or microbiological ingress post process
Metal	Cans and tins	Pinhole	Product leakage and/or pressure loss (carbonated drinks)
		Sharp edges	Consumer incident leading to claim

21.2.2 Single-use (one trip) packaging

Packaging intended for single-use may be made from any of the materials or combinations of materials employed by the industry. Whilst suitability for recycling is not a question appropriate to this chapter, it is worth noting that ultimately brand value for brand owners, retailers and consumers may be affected, for ill or good, by choice of material. This is especially true of single-use packaging which inevitably raises the spectre of land-fill disposal where recycling is not possible.

There may be occasions when a conflict arises between product protection or shelf life, and environmental impact. This is further complicated by the reduction in the use of packaging being sought by manufacturers, retailers and legislators alike. Similarly the use of materials that are readily recycled is being encouraged. This trend makes the role of HARM more important than ever. Consumers are often cited as the drivers of such developments but the greatest pressure probably comes from organised sources in conjunction with the media. Even at its most simple, packaging can extend shelf life and control potential spoilage. For example, shrink-wrapping a cucumber with polyethylene greatly increases its life in-store and at home yet there have been moves to prevent this on so-called environmental grounds. The cost/benefit case for such packaging use may be overwhelming but often perceptions outweigh facts. A similar case can be made for other more sophisticated techniques that extend shelf life, reduce spoilage losses and improve food safety such as vacuum packing and modified atmosphere packaging (MAP).

The contribution that HARM can make is obvious. It can help in finding the balance between protecting the product, protecting the consumer, and protecting brand value. Some compromise is inevitable. When the performance of packaging is linked to food safety there is less scope for debate. Package types such as cans and retortable flexible pouches, where total integrity is mandatory, have an exemplary record of safety. It is in everyone's interest that this reliability be sustained. There will always be a need for those responsible for commissioning and developing new packaging designs, materials or uses to consider all of the implications. Carrying out a hazard and risk analysis must be part of the process.

21.2.3 Returnable transit packaging

Returnable (or reusable) packaging makes an environmental case for itself. It is mainly used as part of the supply chain for ingredients, components, produce and products. There are few examples of consumer packaging that are reused. Examples of RTP range from the ubiquitous timber pallet to complex multi-material constructions for fragile and high-value manufactured components and assemblies. The largest numbers of RTP types are injection moulded plastic crates used by retailers for fresh produce and meat. A typical retailer pool of these can exceed 10 million units. Figure 21.2 gives a representation of the life-cycle of RTP packaging. Successive storage, transport, recovery and maintenance are common to all types of RTP. Ruggedness is an essential characteristic and in applying HARM is often the primary consideration.

It has already been noted that most types of RTP do not have an interface with the consumer. Generally a hazard and risk analysis will deal with fitness for purpose and protection of contents. The exception is types that are used to contain food. For these, part of each 'trip' includes a wash/disinfection process that is comparable in its thoroughness to food industry practice. An example of a hazard and risk analysis based on a food crate wash line is given in Section 21.4.

21.2.4 Packaging performance

It is essential that packaging is able to sustain its characteristics throughout its life-cycle. The physical challenges that need to be taken into account are often numerous and/or unpredictable. A range of tests is available dealing with structural and material adequacy. Structural tests include drop, vibration, compression and stacking. For materials, adhesive and weld strength, tensile strength, abrasion resistance, ink adhesion, etc., are applicable. More information about the nature and use of such tests is given in Chapter 18. HARM can make a useful contribution to this by identifying likely challenges and thus suggesting which testing methods should be applied. Factors that might be taken into account include:

- product value
- physical characteristics
- product fragility
- mode of transportation
- single-use or RTP

- budgetary or cost considerations
- packaging materials choice/limitation.

Again, the importance of a team approach is clear. The team must be able to draw on market experience and technical knowledge. Customer requirements will be part of the mix, especially when decorative and presentation aspects are important.

21.3 Prerequisite systems and controls

21.3.1 The prerequisites

Management systems that make use of formal HARM or HACCP must ensure that a number of prerequisite requirements have been satisfied (United States National Advisory Committee on Microbiological Criteria for Foods, 1997; the British Retail Consortium/IoP the Packaging Society *Global Standard for Packaging and Packaging Materials* – hereafter the 'Global Packaging Standard' – British Retail Consortium/ IoP the Packaging Society 2011). Prerequisite measures are those controls that deal with hazards and sources of hazard that may affect the product at several or all of the stages of production and delivery. HARM is more focused; it deals mainly with definable points in the manufacturing process upon which the safety, legality and integrity of the product may rely. There is no firm dividing line between prerequisites and HARM. Most industry Codes of Practice and Standards provide guidance in this respect, but each case must be dealt with in its own right. Table 21.3 provides a guide

Table 21.3 Prerequisites to HARM

Prerequisite	Example requirements
Premises	Buildings shall be located, constructed and maintained according to appropriate design principles to assure the maintenance of standards that enable product safety and legality to be achieved
Suppliers	The company shall ensure that suppliers have in place effective quality and product safety management systems
Specifications	There shall be written specifications for all raw materials, agreed with suppliers
Equipment	Equipment shall be constructed, installed, calibrated and operated so as to ensure that product will consistently meet specification
Maintenance	Planned preventative maintenance procedures shall be in place
Cleaning	Cleaning of equipment and premises shall be the subject of written procedures, schedules and records
Personal hygiene	Employees and visitors/contractors shall follow written requirements for personal hygiene
Training	Employees shall receive documented training in all relevant aspects of their work
Receiving, storage and dispatch	Raw materials and products shall be stored under clean conditions with documented controls for location and disposition
Traceability and recall	Materials and products shall be recorded in a system which allows rapid and accurate traceability to source and recall from customers
Pest control	An effective pest control programme shall be in place

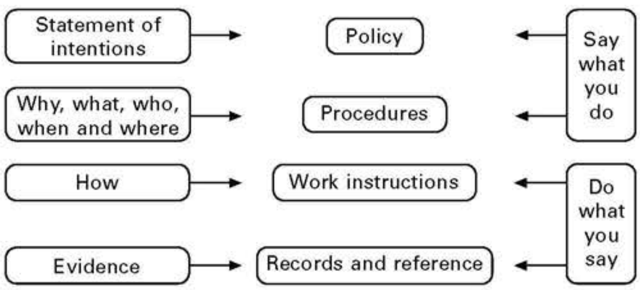
to aspects of the manufacturing environment, facilities and operational arrangements that are generally dealt with as prerequisite to HARM.

21.3.2 Management systems

Well developed management systems supported by authoritative third-party certification are the most convincing way to demonstrate compliance with legal requirements and industry standards. There are two determinants for the adequacy of such systems: firstly, a basis in good practice for the relevant industry sectors often sourced from trade associations or government bodies; secondly, the robustness or 'auditability' of the system, and the records it generates as evidence of effectiveness. The structure of management systems has now reached an almost classic status with a hierarchy of documents having specific functions at each level. Figure 21.3 illustrates basic structure and functions of documents that form parts of a management system.

Integrated management systems, whereby the requirements of several technical standards and industry sector-specific criteria are documented (on paper or electronically) and managed as a single entity, have become commonplace. In such cases a policy statement will be very general, referring to company objectives. It is at the procedure level that integration is most focused. For example, many of the process monitoring and controls called for by HARM will be common to those of the quality management system. Health and safety procedures will also overlap with HARM to some extent. As an example of this we can consider prevention of product contamination during manufacture. Contaminants of concern are normally considered as falling into three categories: physical, chemical and (micro)biological. Such contaminants, if poorly controlled, can have quality and operator safety implications, as well being potentially hazardous to the consumer. Examples of procedures that might be developed to control potential contaminants are given in Tables 21.4, 21.5 and 21.6.

More detail of typical prerequisite requirements is given in the BRC Global Packaging Standard. It should be noted that both HARM-based management systems and the associated prerequisite controls may have significant legal implications. The defence of 'due diligence' was given prominence as a result of its incorporation in the UK Food Safety Act 1990 and has been cited frequently since. The essential aspect of this is that any manufacturer or supplier may have a defence in law should he be able to convincingly demonstrate that all reasonable precautions were observed prior to



21.3 Structure and functions of a management system.

Table 21.4 Physical contaminants and procedural controls

Potential contaminant	Typical procedure
Glass (e.g. windows, lights, screens, watches)	Broken glass and brittle materials Internal hygiene inspection Personal belongings
Timber (e.g. tables, internal structures, tools, pallets)	Pallet condition Internal hygiene inspection Transport, storage and distribution
Dust and dirt (e.g. machinery, building, lint materials, carried from exterior)	Cleaning Maintenance hygiene Internal hygiene inspection
Paper, card, adhesive tape (e.g. board and tape engineering, documentation)	Maintenance hygiene Internal hygiene inspection
Blades and sharps (e.g. knives, needles)	Control of blades and sharps
Maintenance debris (e.g. wire insulation, machine parts, metal cuttings)	Cleaning Maintenance hygiene Internal hygiene inspection
Items from incoming goods (e.g. metal and plastic items)	Inspection of incoming goods
Personnel (e.g. hair, fibres from clothing, jewellery)	Personnel Personal belongings Training
Pests (e.g. rodents, flying and crawling insects, birds)	Pest control Internal hygiene inspection Inspection of incoming goods

Table 21.5 Chemical contaminants and procedural controls

Potential contaminant	Typical procedure
Cleaning chemicals (e.g. detergents, solvents)	Cleaning
Lubricants (e.g. oil, grease, aerosol sprays)	Cleaning Maintenance hygiene
Odour and taint (e.g. solvents, perfume, disinfectants, preservatives, vehicles)	Cleaning Inspection of incoming goods Personnel Personal belongings Internal hygiene inspection
Non-approved materials (e.g. agents and chemicals not on approved list)	Inspection of incoming goods Supplier assurance Product recall
Water (e.g. from roof leaks, spillages)	Internal hygiene inspections Inspection of incoming goods

any occurrence and a resulting alleged offence. A HARM-based management system would thus constitute a contribution to such a defence. Chapter 4 on legislation gives information relating to legal requirements that impact on packaging manufacture.

Table 21.6 Biological contaminants and procedural controls

Potential contaminant	Typical procedure
Personnel (e.g. incorrect use of protective clothing, dirty hands)	Personnel Training
Pests (e.g. contamination by droppings or dead bodies)	Pest control Internal hygiene inspection
Dust and dirt (e.g. contamination from equipment and environment)	Cleaning Maintenance hygiene Internal hygiene inspection
Materials (e.g. contaminated packing and raw materials)	Inspection of incoming goods Supplier assurance
Damp (mould growth) (e.g. goods affected by water during storage/ transport)	Internal hygiene inspection Inspection of incoming goods

The ability to demonstrate due diligence is one of the fundamental reasons for adopting the HARM approach. It has become a routine customer requirement and is incorporated in several technical standards including those that apply to packaging, storage and distribution. The contents of such standards are dealt with in more detail in Section 21.5.

21.4 Hazard identification and risk assessment

21.4.1 Hazard and risk analysis

It is often convenient to consider hazards in relation to the packaging/product, and/or the consumer as distinct issues. This distinction is most important when the product packed may compromise the consumer as a result of contamination during manufacture, or due to a defect. In most instances the manufacturing controls that deal primarily with quality parameters also have relevance to fitness for purpose in general, and consumer protection in particular. It is normal for a hazard and risk analysis to be carried out in circumstances where a mature quality management system already exists. Herein lays a dichotomy. The existing, proven, controls might be assumed to provide sufficient assurance of product integrity and safety. The system of which they form a part will probably be based on many years of production and customer experience. On the other hand, testing that system by rigorously applying hazard and risk analysis is as likely to uncover deficiencies, as to confirm adequacy.

The process of hazard and risk analysis must be carried out in a rational and disciplined way. It is vital that each stage is documented to an extent that confirms competence of the individuals involved, and credibility of outcome. To this end there are a number of requirements that must be met. The commitment of senior management is a fundamental requirement. A properly conducted analysis will require resources of people and time which also equates to cost. Such is the complexity of the task that a multi-disciplinary team will be required. If a sufficient level of skill and knowledge is to be available, then several senior members of staff will be required to commit their time. In some circumstances the use of external experts is desirable or necessary. For example, a manufacturer of packaging destined for the food industry is unlikely to have a staff microbiologist. It should be remembered that whilst an external expert may contribute to the analysis and development of associated management controls, subsequent operations will be the responsibility of the company.

As with any teamwork, it is necessary for a leader to be identified. This individual will have overall responsibility for the progress and outcome of the analysis. Such responsibility must be supported by adequate authority delegated from the highest level in the company. The authenticity of support and authority given to the team leader is one measure of management commitment. The team leader and the team should receive appropriate training in HARM techniques. There are numerous organisations offering such training. Any worthwhile prospective training provider will be able to offer several reference clients for whom they have worked and this simple test should be applied.

The formation of a HARM team cannot be regarded as a one-off exercise for the sole purpose of carrying out the hazard and risk analysis. Like any component of a management system, the controls developed and introduced through HARM will require continuing review and revision. Consequently the system must include reliable arrangements for keeping the team informed of changes to the factory, equipment, products and customer requirements so that these can be reflected in the HARM controls. The general approach to hazard and risk analysis is similar for all applications of the methodology. The working examples used in this text are applicable to hazards to the consumer that might arise from failures in the manufacturing process. They are equally relevant to hazards to the manufactured product during the product life-cycle as discussed in Section 21.2.

21.4.2 HARM development

Records of the initial HARM development work should include a list of the team members and their job titles. Each stage of the process thereafter must be recorded. The process itself has been outlined in several published versions which are, in essence, the same. The following list of stages is based on these. These steps are:

(a) Describe the product(s), intended use, and consumer/user.
(b) Decide the scope of the HARM system and draw up an accurate diagram of the process flow(s).
(c) Identify and assess the possible hazards due to process failure at each process step.
(d) Introduce or confirm monitoring and control at critical process steps.
(e) Validation and verification.
(f) HARM review.

Describe the product(s), intended use, and consumer/user

Where a number of products that differ in materials, production methods or intended use are manufactured, it may be necessary to conduct more than one analysis. The decision as to the significance of any differences and whether these merit separate consideration should be made by the team. It may be that, in the light of subsequent stages of the HARM development, this decision will merit review. The team leader should note this and call for review as appropriate. The intended use of the product and any potential consumer impact should take account of possible consumer vulnerability. For example, a label for infant food, or one where confusion over composition (ingredients) of contents could arise, may require special attention to text layout and wording.

Decide the scope of the HARM system and draw up an accurate diagram of the process flow(s)

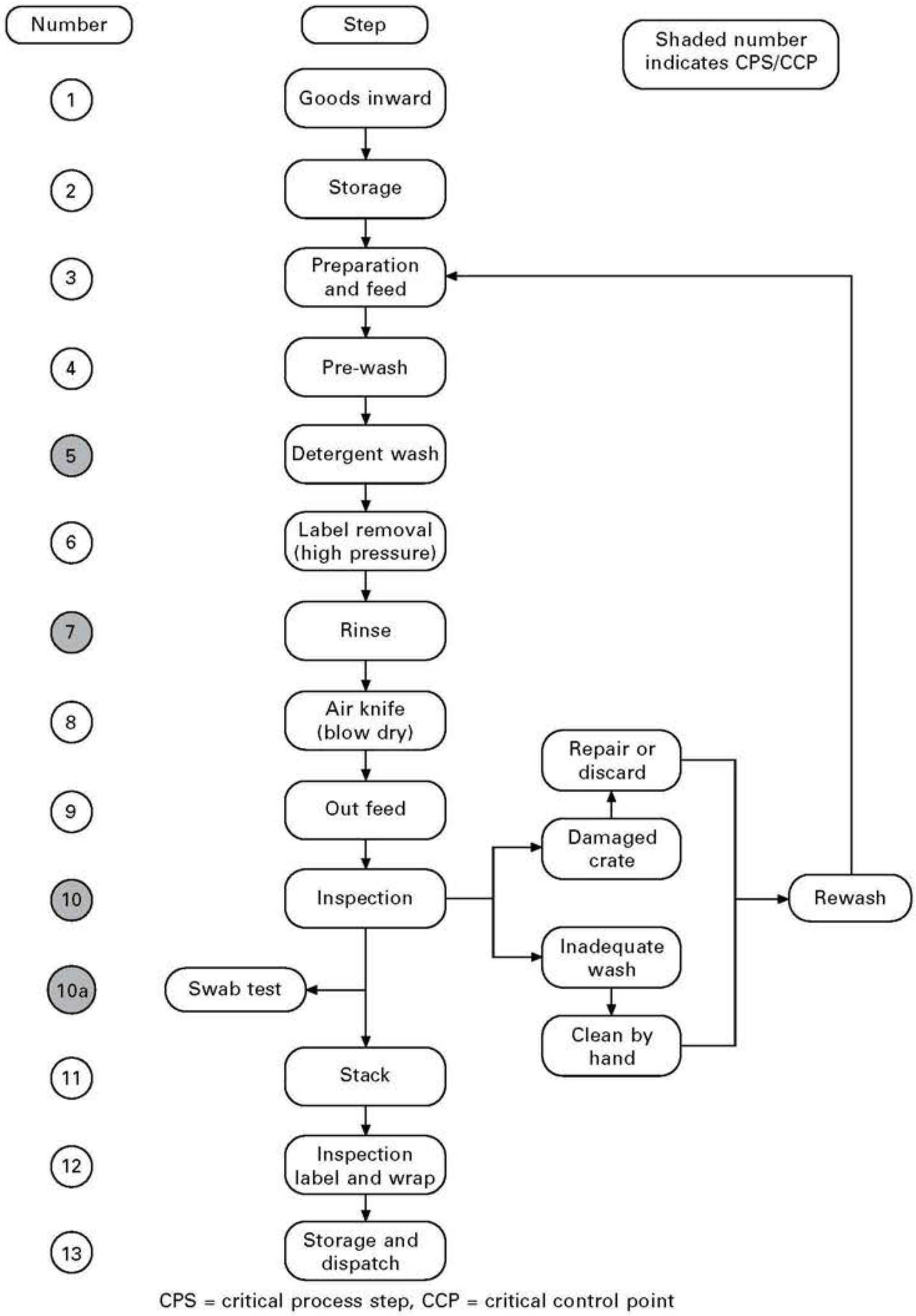
Scope in this context is the proportion of the product life-cycle to be covered by the HARM system. This needs careful consideration as some parts of the product life-cycle may not be completely under the control of the company. As an example of scope, it could include the manufacturing process from reception of raw materials to dispatch of finished products. In some cases the scope may be extended beyond these limits. The effectiveness of prerequisite measures in dealing with possible hazards not under the company's direct control should also be taken into account when establishing scope. Processes vary in complexity and in some cases aspects normally dealt with as prerequisites may require full analysis.

Diagrams or flowcharts that describe a process vary in the amount of detail they include. This will be influenced by the complexity of the process as well as the sensitivity of the end use of the product. Generally, a flowchart to be used as part of HARM in packaging manufacture need not be highly detailed. The number of process steps identified will normally be between eight and fifteen and the flowchart should include ancillary processes in addition to the main line of flow, appropriately linked.

Hazard and risk analysis allows for more than one hazard to be identified at each step; hazards should not be considered at this stage. The objective should be to accurately and adequately describe the process or processes without consideration of hazards. It can prove helpful to conduct an on-site comparison of the flow diagram with the actual factory arrangements. The involvement of personnel not familiar with the process can help to avoid assumptions about the validity of the diagram. An example of a flow diagram is given in Fig. 21.4.

Identify and assess the possible hazards due to process failure at each process step

This is the most problematic aspect of HARM development. The challenge is to decide which of the hazards is of sufficient severity and likelihood to merit special attention. Process steps where such hazards are identified are often described as 'critical control points' (CCPs) or 'critical process steps' (CPSs). A number of methodologies that aid this decision have been developed. It is important to recognise that such methodologies are best used for guidance in reaching the 'criticality' decision.



21.4 Example process flowchart (RTP washing).

Ultimately that decision will be a matter of judgement as well as analysis, again emphasising the importance of using a team in arriving at conclusions. A number of 'decision trees' have been available, derived from that first published by Codex Alimentarius for use in HACCP development. Codex Alimentarius have recommended caution in the application of their decision tree, implicitly recognising that it may have been misapplied in the past. Such misapplication can result in large numbers of CCPs being identified resulting in excessively large and complex and potentially unworkable HARM/HACCP systems.

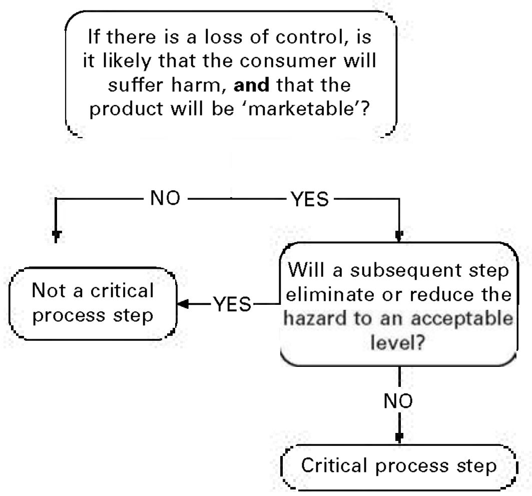
HACCP decision trees were devised to deal with process steps in the food industry. Given the inherent biological stability of packaging materials, it is possible to simplify the decision tree without compromising its validity. An example of a simplified decision tree is given in Fig. 21.5. The simple decision tree adds another consideration for inclusion in the analysis. If loss of process control will render the product recognisably out of specification to an extent that it will be unsuitable for sale, then that point in the process may not be critical.

In addition to the use of the 'decision tree' for guidance in determining critical process steps, a 'scoring' system is often adopted. One such system is set out below. Note that the essentially subjective nature of the criticality decision is not made objective by the adoption of such a scoring system. Critical process step decisions are always to some extent judgemental.

What would be the consequence of the hazard occurring (the Severity)?

High	3	Death or serious injury
Medium	2	Temporary disability/minor injury
Low	1	Discomfort
None	0	Negligible consequence

Similarly, the likelihood of occurrence can be given a rating as follows:



21.5 Simplified 'decision-tree'.

How likely is the hazard to occur (the Risk)?

High	3	Likely to happen
Medium	2	Could happen
Low	1	Unlikely to happen
None	0	Cannot happen

The score for each identified hazard/control is calculated using the following formula:

Score = Severity rating × Risk rating

The range of resultant scores is 0 to 9. A process step should be considered to be potentially critical where the score is *higher* than 2. If a score of '3' is a result of the estimate of risk being '3' and severity '1', then the answer to the question 'Has this ever happened?' should form part of the judgement. Documentation of the decision process can be by tabulation of process steps and each aspect of the analysis. An example of this is given in Table 21.7.

Introduce or confirm monitoring and control at critical process steps

For each process step identified as critical, it is necessary to confirm that current system controls are adequate where they exist, or to take action to achieve adequacy. This might be done by improvement of existing controls or development of new procedures and work instructions that will lead to effective control. It is normal to record this. Table 21.8 is an example of how this may be presented.

In order to demonstrate that all of the requirements of HARM have been fully met, it is necessary to state for each critical point the method and frequency of monitoring,

Table 21.7 Example hazard analysis chart, RTP (retail crates) washing

Process step #	Hazard(s)	Type[a]	Hazard analysis		CCP decision	Reason (Decision Tree?)
			Severity	Likelihood		
1	None identified				N	Pre-process of incoming soiled crates
2	None identified				N	Pre-process of incoming soiled crates
3	Potential contaminants not removed	M P C	2	0	N	Subsequent steps are specifically intended to deal with this hazard
4	Potential residues due to process failure	M P	2	1	N	Subsequent steps are specifically intended to deal with this hazard
5	Potential residues due to process failure	M P	2	2	Y	Score of 4; process parameters under direct control at this step

[a]M (microbiological), P (physical) or C (chemical) as appropriate.

Table 21.8 Example HARM control chart, RTP (retail crates) washing

Process step #	Process monitoring	Frequency	Target	Tolerance	Corrective action	Document[a] References/ records
5a	Temperature measurement	4 times per shift	55°C	± 5°C	Check m/c parameters and functionality. Re-process	TP011 TF004 WI004
5b	Detergent concentration measurement	Continuous by probe. Manual check if step 10 or 10a dictates	½ % in water	± 10%	Check dosing equipment function. Re-process	Instrument calibration TP011 TF004 WI001
7	Temperature measurement	4 times per shift	75°C	± 5°C	Check m/c parameters and functionality. Re-process	TP011 TF004 WI004
10	Physical inspection	Constant during process	No visible residue	Nil	Reject and re-process	TP011
10a	ATP Swab testing	4 times per shift	<150 rlu	+150 rlu	Re-process as necessary	TP011 TF004 WI003

[a]TP = technical procedure, TF = technical form, WI = work instruction.

target and tolerance values, corrective actions that will be taken if tolerances are exceeded, and the identity of related documents in the management system.

Validation and verification

In this context validation is a test of fitness for purpose of the documented system, its procedures, work instructions and records. It is the process of confirming that they are capable of achieving the intended control of hazards. Validation should be undertaken prior to the implementation of the control measures. It is best if validation is at least overseen by a person or persons who were not directly involved in system development although this is not essential. Validation can include carrying out tests to the product to confirm that the parameters set are being met. This might include microbiological testing or chemical analysis as well as dimensional checks, where these could have a safety-related effect on product performance.

Verification is the process for confirming that the system is meeting its objectives in practice. This is carrying out mainly through internal audits. An audit programme must take account of HARM, with verification one of its specific activities. Frequency of audit of critical process steps may be greater than that of other parts of the system where this is deemed necessary. Verification seeks to establish the extent to which the management system is correctly implemented, and meeting its intentions.

HARM review

Management systems are subject to periodic review usually by report to a review group including senior management. The HARM system is part of this, taking account of the results of internal and external audits, and customer concerns and complaints. The reports should identify any need to update or improve the HARM system, and any trends in the occurrence of incidents linked to product safety. Actions taken to address these issues should also be reported. Incidents where critical limits have been exceeded merit special attention and corrections applied and corrective and preventative actions must be fully documented. It is the role of the review group to confirm that satisfactory outcomes have been achieved.

21.5 Industry technical standards

21.5.1 The standards

There are three technical standards relevant to packaging manufacture, storage and distribution that require a HARM or HACCP system as part of compliance and certification. Hazard and risk analysis, and management, can be applied to other standards. For example, the BS *Occupational Health and Safety Standard* (BS OHSAS 18001:2007) calls for analysis of hazard and risk (although the methodology differs from that set out here). HARM methodologies can also be of value when establishing controls for compliance with quality and environmental standards.

Table 21.9 lists the relevant standards and gives an indication of their scope. The BRC/IoP *Global Packaging Standard* and the BRC *Global Standard for Storage and*

Table 21.9 Industry technical standards

Standard	Scope	HARM requirements
BRC/IOP *Global Standard for Packaging and Packaging Materials*, Issue 4, February 2011	Manufacture of packaging and packaging materials for food and 'hygiene sensitive' products (includes other food-contact items)	Mandatory for all categories of packaging/materials
BRC *Global Standard for Storage and Distribution*, Issue 2, September 2010	Pre-packaged and loose food products, packaging materials and consumer products (includes wholesale and contracted services such as cleaning of returnable packaging)	Mandatory with variations for consumer products Some technical guidance is appended
BS EN ISO 22000:2005, 'Food safety management systems – Requirements for any organisation in the food chain'	All organisations, regardless of size, that are involved in any aspect of the food chain	HACCP is a mandatory requirement

EU Regulations (No. 178/2002, No. 852/2004) legally oblige food storage and distribution companies to ensure systems are in place to supply safe and legal products.

Distribution (British Retail Consortium, 2010) contain detailed requirements for the conduct and recording of hazard and risk analysis for the establishment of HARM. In addition the BRC standards require the use of hazard and risk analysis in deciding the level of control appropriate for meeting some of the standards' requirements, according to the degree of risk encountered. Examples of this include the frequency of pest contractor visits and the identification and control of risk of microbiological contamination.

The BRC *Global Packaging Standard* was written so as to give sufficient flexibility to embrace the wide range of packaging types and potential hazards and risks. This was achieved by enabling companies to seek exemptions from some of the standard's prerequisite requirements by using hazard and risk analysis. For an exemption to be valid, a company must demonstrate that hazard severity and risk likelihood are such as to make compliance with the specified requirement inappropriate or unnecessary in given circumstances.

Although ISO 22000 (British Standards Institution, 2005) is nominally a food safety standard, its title does indicate broad scope and some sectors of the packaging industry have adopted it. The washing of retail crates is an example of this. RTP conditioning companies do not manufacture packaging and thus fall outside of the scope of the BRC/IoP Packaging Standard. Many packaging manufacturing companies have adopted ISO 22000 and become certificated to it. There is a perception that there are benefits in it being international in its derivation and acceptance.

ISO 22000, like ISO 9001 with which it has been devised to be compatible, is technically non-prescriptive. In this respect it differs from the BRC Standards which are technically detailed and prescriptive. In order to give direction to companies seeking to comply, ISO 22000 requires that reference be made to appropriate sources of guidance. These include the Codex Alimentarius Commission (Codex) principles and codes of practice (United Nations Food and Agriculture Organisation, 2003), and national or sector-specific standards. There is a paradox here in that the obvious sector-specific standard for packaging manufacture is the BRC/IoP *Global Packaging Standard*. It may be that customers from the food industry will ultimately prefer their suppliers to be certificated to ISO 22000 because of its clear food remit. Some companies have adopted certification to both standards in order to meet differing requirements of customers.

21.5.2 Using the standards

The practical impact of adopting any standard is much affected by interpretation and implementation. This can result in the management systems and operational circumstances of companies certificated to the same standard appearing to differ. Whilst the development and introduction of industry standards has always been promoted as a way of achieving adequate control and consistency, many customers continue to carry out technical visits. Some of the variability between certificated companies is a reflection of customer preferences. Often a customer will require more demanding site standards or production controls in specific respects than are judged to be necessary for compliance with a standard.

Certification to a standard implies complete compliance. Since all certificated companies are in that position, compliance is often seen as meeting the minimum that is acceptable. Many companies choose to go beyond that, as a result of a determination to be seen to be leading their sector, or to demonstrate excellence to customers.

Packaging companies may be in one of three circumstances when working with a technical standard. They may already be certificated, working towards certification, or in the process of changing from one standard to another. These alternatives are shown in Figure 21.6.

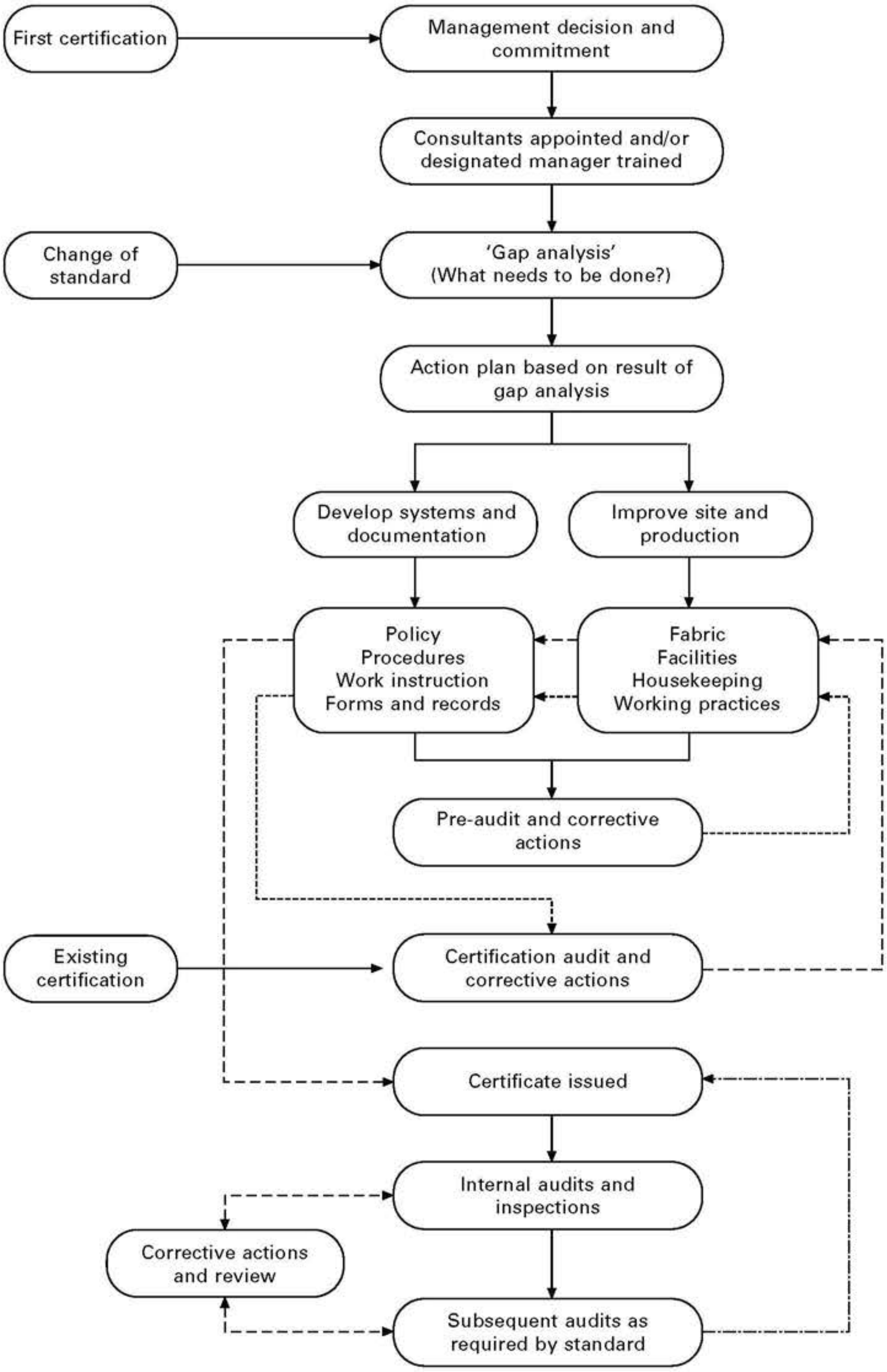
All technical standards require the commitment of management. Organisations working towards certification, using a standard for the first time, must support their objective with adequate resources. Unless the individual designated to lead the exercise has demonstrable previous experience then training may be necessary. Often the use of a consultant will provide an experiential route to developing the required knowledge and skills without the need for formal training. The best approach can only be decided by the management team and initial informal discussions with certification bodies and consultants will guide this. Familiarity with the contents of the chosen standard and the process of certification can only be achieved in the light of experience. Training will help this. A properly conducted training course, based on interactivity as well as the imparting of knowledge, and shared with others with a common interest, can be invaluable.

The size of the task is best assessed by carrying out a gap analysis. That is, comparing the current position with what has to be achieved. This enables an action plan to be drawn up. There are two main areas of activity that need to be planned. Firstly, some management system documents may require revision. Additional documents are also likely to be needed. Secondly, the site, factory, equipment and personnel management will have to be reviewed to ensure compliance. Most certification bodies will be seeking evidence that staff at all levels have received training commensurate with their responsibilities.

When the above work is complete or nearing completion, it is normal to have a pre-audit carried out. Many certification bodies are able to offer this, as are independent consultants. The pre-audit is a final critique of the system and site prior to the certification audit. If an independent consultant is used, it can also serve as the first internal audit, evidence of which is a requirement of certification. The system documentation, especially that concerned with the non-conformance, corrective action and review processes, should be in use at this stage to subsequently provide objective evidence of functionality to the certification auditor. Similarly, records of process parameters, cleaning activities, pest control visits and so on will be essential.

21.5.3 Certification

The first certification schemes for hygiene and product safety in packaging manufacture were launched in 1990. During the following years a number of competing schemes were offered. None of these early certifications had links to accreditation bodies such as the United Kingdom Accreditation Service (UKAS). These schemes relied on being accepted by the packaging industry and their customers, and the credibility of the

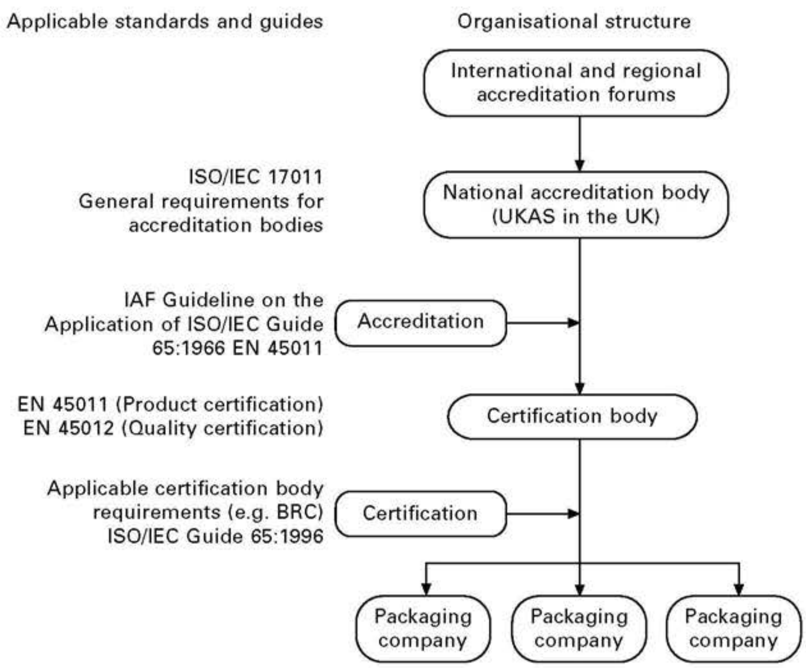


21.6 Certification process.

organisations that operated them. The first issue of the BRC/IoP Packaging Standard was published in 2001, following development by a committee with representation from the packaging industry, their customers and the certification organisations. Among the reasons for the development of the BRC/IoP Standard was drawing together the various competing certification schemes into a single common position. In addition, certifications were required to be operated by accredited certification bodies. This continues to be the position for all the BRC Standards and ISO 22000.

The terms accreditation and certification are often confused. Stated simply, a company is *certificated* by an accredited certification body. A certification body (of which there are several in most countries) is *accredited* by a National Accreditation Body (in the UK this is the United Kingdom Accreditation Service – UKAS). These relationships are conducted according to internationally accepted standards and guides. They are illustrated in Fig. 21.7.

There can be no doubt that during almost 20 years since the introduction of industry standards dealing with hygiene, and hazard and risk management, there has been a transformation in operational arrangements in the packaging industry. Sites in the UK and throughout the world have developed, in some cases transformed, their working environments and production controls. Factories have become more pleasant places to work, to the benefit of all involved. Improvements to product integrity have been an inevitable consequence.



21.7 General arrangements applying to certification and accreditation.

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