

Chapter 5

Secondary Packaging Components

Secondary packaging components are a somewhat arbitrary definition of devices that are added to the main structure of a package. They are typically added to provide specific functions such as closing and dispensing, communicating product information, ease of use by the consumer, or structural and esthetic enhancement. As packaging systems have developed into more proactive and complex devices, these secondary components have become more important in offering extended product quality, shelf life, and utility.

Secondary packaging components became a necessity the moment that prehistoric people noticed that their gourds and pottery flasks would leak unless they were closed up somehow, and that leaves wrapped around food would spring open unless pinned with a twig. Package closures – the devices that both seal and allow consumer access to the product – are thus arguably the oldest added component in packaging.

Closures

Closures have been made from natural materials since the earliest times. Carved wooden bungs in barrels and natural corks in wines and spirits still exist in this vein, but for most mass-produced applications these have been replaced with closures that are more highly engineered and offer greater functionality. Threaded closures were available on Mason glass jars, patented by John Mason in 1858, from the middle of the 1800s onward, and depended on a shallow thread on the glass jar molded in a multipart mold. This then required a matching, threaded ring with a gasketed plate to form a two-piece lid that is still manufactured for home canning and is used for some commercial products to reinforce a “homemade” image.

The first highly engineered package closure designed for high-speed assembly was arguably the crown cap by William Painter, who patented the design in 1892. This was novel in that it relied on a seal that was formed by bending the edges over the edge bead of the finish on a narrow-neck glass bottle using a pressure die. Previous cap designs relied on a secondary fastening device, usually a strand of wire, to hold the cap in place, and the advent of the crown cap that had a sealing gasket and could be applied at relatively high speeds assisted in the mass production of bottled goods. Neither of these inventions was a particularly precise solution to the sealing problem, and both depended on a gasket material to complete the seal. Twist-off variations of the crown cap were attempted almost immediately after their introduction and finally became widely implemented in the 1970s, although their use is sometimes avoided by bottlers trying to maintain a non-mainstream market image.

As moldable polymers became available, thermoset and then thermoplastic compounds were used to produce threaded closures – one of the few remaining applications of traditional

thermoset polymers in packaging, although these still relied on an internal liner to complete the seal with the container. With the development of tough thermoplastic compounds, particularly polypropylene, closures began to be responsible for more and more package functionality as these materials would resist repeated opening and flexing of dispenser cap covers without fracturing. These materials also have allowed the development of *linerless* closures that rely on molded sealing ridges in the interior of the cap that compress against the container finish to provide a seal.

Caps

Caps may still be pre-fabricated of stamped metal, but with the exception of the crown closure and large, lug-finish lids for thick products like jams and spreads, many of these markets have largely been given over to molded plastic closures. An exception are rolled-on metal caps supplied as an unthreaded, cup-shaped blank fitted with a liner, which is formed over the finish on the container using rolling dies that use the threads on the container as part of the forming process. These are predominantly used for glass containers, particularly wine and spirits, and have begun to replace corks in the wine market because of their inertness and lack of contaminants, though they still carry a *déclassé* image with many consumers, despite their better performance.

Thread Profile

Because of the ductile nature of plastic closures, the thread profile for finishes on plastic materials may be different than traditional thread profiles for glass and metal containers. These threads are designed to minimize distortion due to viscoelastic creep of the material, and have mating flat faces between the container thread and the threads on the closure. Use of these types of threaded closures with containers, particularly glass jars and bottles, with the older style of thread will result in cap jamming or premature loosening and leakage. Traditional containers can be specified with a modified thread profile to accommodate the new cap types.

Liners

Liners, when used, are typically composed of two components: a backing, which is made of a compressible, elastic, or viscoelastic material; and a facing that contacts both the product and the sealing edge of the package finish. Facing material must be compatible with the product and must provide the necessary degree of protection against permeation and leakage, because with a metal cap and glass bottle, it is the only path for oxygen or other material to affect the product. Some beer manufacturers have incorporated oxygen scavengers into their crown cap liners because of this. Additionally, since lined caps are often threaded on, the facing must resist tearing or distortion as it rotates onto the finish, although secondary lubricants may be used for this purpose.

Torque loss – the reduction of force needed to unscrew a closure – may occur as the backing material is over-compressed, or exhibits creep or viscoelastic flow over time, and can result in the loss or contamination of product. Generally, torque loss tests are done after conditioning under standard conditions using ASTM D2063 or D3198 protocols or their equivalent, but it may be necessary to do field studies of the post-distribution containers to develop an accurate picture of whether the closures are sealing properly or not.

Child-Resistant Packaging

Child-resistant packaging, which was required for many types of products after Congress passed the Poison Prevention Packaging Act in 1970, relies heavily on specialized closures. The act requires child-resistant (CR) packaging of any household substance that may cause serious injury to children if handled, used, or ingested. Such packaging must be difficult for children under the age of five to open while (contrary to many opinions) still being accessible to adults.

Some substances included in 16 CFR 1700.14 & 1700.20 are: acetaminophen, ibuprofen, prescription and controlled drugs, as well as non-ingested household products such as paint solvents, furniture polish, and certain glue removers. The test protocol to establish a closure as child resistant is rather involved and leads to a limited number of types in production. The protocol requires that 200 children between the ages of 42 and 51 months, working in pairs, are allowed five minutes to open a package. For those who cannot open it the first time, a single non-verbal demonstration is given and they are allowed another five minutes. Effectiveness must be 85% without demonstration and 80% after a demonstration, with a separate adult test having a 90% or better success rate.

Some controversy has occurred with CR packaging as a result of general frustration with difficult-to-open packages, and because handicapped and elderly customers – particularly those with arthritis – often may not be able to open packages of critical medicines. To adapt to this challenge, pharmacies have adopted flip closures that can be either child-proof or not at the discretion of the customer, and manufacturers have begun to include closures with fins or textured surfaces that may be more easily opened by customers with limited manual dexterity.

Glues and Adhesives

Glues and adhesives are typically used as a means of fixing materials together, either as a means of package construction or to attach a feature or product. By definition, glues are derived from natural sources, such as milk or cow hides. Adhesives are based on polymers that are chemically synthesized, but most people use the terms glue and adhesive equivalently, although the distinction may be important in technical standards and specifications.

Simple glues such as waxes, resins, hide glues, and casein (milk protein) based adhesives have been found in many archaeological sites, and recipes for making and using them are mentioned in Greek, Arabic, and Roman texts. Many of these basic types of glue still exist but have been supplemented or superseded by newer adhesive formulations that include synthetic polymers and additives that allow more careful control of properties and retard the aging of the bond. The earliest casein adhesives, manufactured by extracting milk protein from skimmed milk by heat and vinegar, are still available as the “white glue” that is often used for school projects and woodworking, and hide glues rendered from rendered animal bones and hides are still used for the assembly of furniture and musical instruments.

Newer adhesive technology has been driven by the need to bond surfaces without mechanical fasteners in industries such as aerospace structures, automobile assembly, and surface-mount electronics. This has prompted a new generation of bonding methods, some of which have been cost-effective enough to find applications in packaging.

The Role of Surface Chemistry in Adhesion and Printing

Substrate compatibility is a fundamental requirement for any type of printing, coating, or adhesive application, because the ink, coating, or adhesive must bond to the substrate’s surface

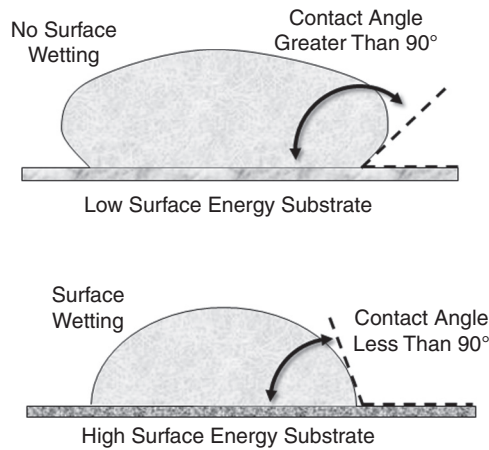


Figure 5.1. Contact Angle and Wetting

in order for the process to be successful. For porous materials, often this is less of an issue than for plastic films that may exhibit a poor match of surface characteristics with the ink, coating, or adhesive. Polyolefins such as polyethylene and polypropylene have traditionally been challenging materials to work with in all types of surface material adhesion applications and usually require surface treatment in order to raise the surface energy of the material enough to overcome the surface tension of the liquid being applied.

This can be illustrated by the concept of *Wetting*, as shown in Figure 5.1. If the contact angle is oblique, the surface energy of the substrate is a good deal less than the surface tension of the liquid, and wetting and adhesion will be very difficult – a principle exploited in car wax and other repellant coatings. On the other hand, if the contact angle is acute, it is an indication that the surface energy is sufficiently larger than the substrate (usually by about 10 dynes/cm). As the contact angle approaches 0° , it is an indication of complete wetting.

To affect the surface energy of films, many treatments may be used, but the two most common are flame ionization and corona discharge treatment. These processes use an open flame or high-voltage discharge, respectively, to achieve this, and each has advantages and disadvantages depending on the material and process. For example, using a thin, flammable film with flame ionization would present a combustion hazard, but corona discharge equipment may create spark-path pinholes in the material in a similar manner to the microperforated films mentioned in Chapter 4.

Both of these methods use a high-energy source to create ionized particles that will partially disrupt surface bonds in the material and create a degree of oxidation and cross-linking that changes the surface chemistry to facilitate improved surface wetting and adhesion. Both treatment effects will dissipate over time as well, so many operations will treat the materials just before use, or have an effective “expiration” date on materials that are treated by contracting suppliers.

Adhesives Terminology

Pot Life: The length of time that a particular adhesive can remain workable. Some adhesives are kept in operating machinery for long periods of time and may degrade due to heat and oxidation.

Open Time: The amounts of time that adhesive bonding surfaces can remain out of contact with one another before a bond will no longer form.

Tack: An initial low-strength bond that is formed upon immediate contact. This is an especially important property in the packaging industry, because high-speed operations require application of a particular component and almost immediate removal of application force.

Hot Tack: The term used for hot-melt adhesives to describe the bonding ability of adhesives that have been applied but have not completely cooled. *Tack agents* are often added to promote this.

Cure: Final forming of a high-strength bond. Cure time is also important in packaging, because packages are often placed in service very quickly after manufacture. In systems where packages are assembled in one operation then used in another, the shipping time between the two operations may be used as curing time for the adhesives used.

Adhesion: A state in which two surfaces are held together by interfacial forces that may consist of valence forces, molecular bonding, or interlocking action.

Mechanical Adhesion: Adhesion between surfaces via interlocking action of fibers, structural features, or adsorbed adhesive components that solidify after joining.

Types of Adhesives

Naturally Derived Adhesives

Naturally derived adhesives are, as previously mentioned, derived from waxes, resins, gums or protein compounds that are subsequently modified to promote stable bonding properties. Although waxes are seldom used except in decorative applications, modified gum structures are quite common.

Starch- and Dextrin-Based Adhesives

Starch, modified starch, and dextrin (an intermediate polysaccharide compound resulting from the hydrolysis of starch to maltose by amylase enzymes [1]) are some of the earliest and still most common packaging adhesives in use. The source of the basic high-quality starches used in adhesives will vary by country (and crop subsidy program), with cornstarch being most common in the United States and potato, wheat, and rice starches most often used in Europe and Asia. Globally, unusual sources of starch such as sago, tapioca, or cassava may be used depending on availability and price [2]. Starch and dextrin adhesives offer the advantages of both high availability and relatively low cost and good adhesion, particularly to porous substrates. Additionally they are non-toxic, biodegradable, and resist heat, oils, and fats, which make them ideal for use with many food products.

Starch suspensions in water do not exhibit useful adhesive properties, so cooked raw starch is seldom used directly as an adhesive in favor of a smaller-chain compounds resulting from acid hydrolysis and modification that produces a more carefully controlled and often thinner starch compound or dextrin, depending on the degree of conversion. Nanoscale starch compounds have shown some applicability as a stable form of raw starch and as a challenger for latex and other laminating adhesives [3].

Starches are composed of two basic molecules, amylose and amylopectin, both with long polysaccharide structures, with amylose typically representing approximately 25% of the total. Amylose is a series of long linear chain structure, whereas amylopectin exhibits a high degree of branching, and only amylopectin is cold-water soluble without further modification. Amylose

can be modified by cooking at higher temperatures (typically above 150°F/66°C) in water or water-formaldehyde solutions, or by modification with alkali. This will produce a dispersion that will form a firm gel at concentrations above 2% and a precipitate below that. Amylose gels are prone to *retrogradation*, the formation of a more highly aligned molecular structure that is accompanied by an increase in viscosity and water expulsion, whereas amylopectin is more soluble and less prone to these changes.

Starch adhesives are manufactured by heating starch in water with either caustic soda or metallic chlorides until gelation – the rupturing of naturally occurring starch granules – occurs, forming a colloidal paste of unmodified starch. If the caustic soda method is used, the adhesive is later acid-neutralized. Starch adhesive viscosity varies markedly with concentration and will cause pumping to become impractical above concentrations of approximately 5–8% and impossible as the unmodified starch becomes a solid with higher concentrations.

Modified starches are treated to resist retrogradation and the previously mentioned viscosity problems, making them more suitable for adhesives use. These treatments include alkali treatment and acid modification to change gelation temperature and viscosity, respectively, and hypochlorite-based oxidation that will produce a high-tack adhesive that is used for both adhesives and paper-sizing additives.

Dextrin-based adhesives are manufactured by heat-treating starch with acid to produce a high-solubility branched polymer with good water solubility. The degree of processing can control the extent of conversion and therefore the stability, viscosity, and strength. The three major classifications of dextrin adhesives are white dextrans, yellow dextrans, and British gums, in order of increasing processing temperature and duration, as well as increasing molecular weight, darkness of color, stability, and resistance to retrogradation [4]. British gums are commonly used for high-strength applications such as shipping tapes, whereas the lower molecular weight white and yellow dextrans are often used for gummed papers and envelopes. Additives and modifiers of starch- and dextrin-based adhesives may be added to affect tack, viscosity, brittleness, drying time, and wetting/rewetting properties.

Jelly Gum Adhesives

Jelly gums are formulated by cooking cohesive starches such as cornstarch in alkali, which produces an elastic gel adhesive that is resistant to immersion in cold water and is thus used in many glass beverage container labeling applications. Problems with these labeling applications on glass containers may arise from interaction with the *cold coating* on the glass discussed in Chapter 4, and are often the result of residual coating interfering with the adhesion of the label adhesive. Other uses may include attaching coupons to packages, inclusion of pages in printed materials, and the attachment of cards and flyers in mailing operations.

Other Gum Adhesives

Nearly any plant or microorganism that can exude or otherwise generate a viscous substance has been examined as a source for adhesives. Some of these, such as gum arabic, guar gum, and xanthan gum, are familiar as food-thickening agents, but there are many plant and microbiologically based gums that are available and may be used. In current uses, the naturally occurring gum components are often used as adjuncts to synthetic adhesives to act as property modifiers or extenders, and some are used for non-packaging applications such as denture adhesives.

Bone, Hide, and Fish Glues

These are based on a water solution of gelled collagen derived from animal (usually beef) hides and bones or cod bones and skin. Fish glues are seldom used in applications other than photoengraving, but hide glues are still used both in assembly operations, such as instrument making and bookbinding, and in some limited applications in packaging. Because of the limited pot life and inferior resistance to moisture, the applications are somewhat limited but are included because of their historical impact and potential for specific, niche applications. Additionally, concerns about BSE prions being transmitted from these base materials, as well as the occasional concern about animal products upsetting some customers have curtailed their use.

To recover the collagen from hides or skins, the raw materials (usually taken from meat- or fish-processing plants) are soaked, then treated with weak acid, and finally boiled several times to extract the collagen as *glue liquor* in the final boiling step. The resultant gel is treated to remove impurities and may be evaporated to increase thickness. Bone glues are produced in a similar manner with the exception of a treatment with acid to remove the mineral components of the bones, leaving only the bone proteins for further processing.

Casein ("White") Glue

Casein glue, commonly known as "white glue" because of its color or "school glue" because it is often used for craft and woodworking projects, is manufactured by precipitating milk casein proteins from milk as a curd using acids, and then neutralizing the acidity to produce a flowable casein glue. Its non-toxic nature and extreme strength for bonding porous structure has made it particularly useful for many types of bonding applications, although the unmodified adhesive may have an unacceptably long bonding time. Many "white glues" that were originally produced from milk proteins have been replaced or supplemented by water-based polyvinyl acetate (PVA) emulsions.

Synthetic Adhesives

Synthetic adhesives in general can be divided into several categories. These would include one- and two-part adhesives as well as anaerobic and moisture-curing adhesives. Although several of these are not used in the packaging industry to any extensive degree, they are mentioned because specialty applications may require their use.

Waterborne Synthetic Adhesives

An emulsion is generally defined as a colloidal mixture of two immiscible substances, and everyday examples include butter (which is a water-in-oil emulsion) and cream (which is an oil-in-water emulsion). Nearly all waterborne synthetic adhesives are emulsions, which are microscopic droplets of the adhesive polymer in water. Generally the emulsions are composed of a dispersed phase (the adhesive) in a continuous phase (water). When these adhesives are supplied as a water-based emulsion, the adhesive can be applied to a substrate, and the subsequent dehydration of the aqueous continuous "breaks" the emulsion particles open, allowing the adhesive bond to form. This has the advantage of allowing complex organic adhesives to be applied without the use of volatile organic compounds (VOC) as solvents that may present a workplace or customer health hazard. The largest part of the market for emulsion-based adhesives are variations on vinyl acetate compounds, predominantly polyvinyl acetate (PVA) and

ethylene vinyl acetate (EVA), along with acrylic and styrene-butadiene (SB) latex compounds that are used in pressure-sensitive adhesives for packaging.

Some of the problems that may be encountered with emulsion-based adhesive systems include emulsion instability as the dispersed phase forms clumps or stratifies by density to the top or bottom of the emulsion, or emulsion “breaking” where the dispersed phase separates completely from the continuous phase as a result of freezing, fluid shear during pumping, contamination, or excessive heat.

Other Types of Synthetic Adhesives

Solvent-Based Adhesives: Solvent-based adhesives usually form a bond as the result of loss of a volatile organic solvent leaving behind a binding agent. Rubber cement is a surviving example of this type of adhesive, but many types that were historically used for package assembly have been replaced with lower VOC content types because of workplace regulations or concerns over solvent contamination of the product itself.

PVA (Polyvinyl Acetate Resins): These are formed by polymerization of ethylene with acetic acid and oxygen, and are commonly used as “carpenter’s glue” that may be used for paper and other absorbent substrates.

Cyanoacrylate Adhesives (“Super GlueTM”): Bond by action of residual moisture in surface or moisture adsorbed from the air. Many types of polymers do not bond well with these adhesives, and the difficulty in handling them makes high-speed application difficult, so they are seldom used in packaging applications.

Polyurethane: These cure on exposure to moisture as well, and are used extensively in vehicular and home assembly, but the expense and difficulty of high-speed automatic application make them unpopular for use in package assembly, although more small-device assembly with these types of adhesives means that packaging applications may be forthcoming.

Hot Melt Adhesives

Hot melt adhesives have a lineage back to the use of naturally occurring waxes to form seals on envelopes and documents. In essence, they are thermoplastic compounds that liquefy when heated, are applied to the bonding surface, and then solidify again after cooling, forming a mechanical bond with the substrate. Unlike most other types of adhesives, hot melts do not rely on a solvent system to carry the adhesive, instead, are systems of thermoplastic resins and additives (typically waxes and *tack agents*) that liquefy when heated. Because of the broad definition of a hot melt adhesive, there is a wide range of formulations available for nearly any application, but most offer the advantage of a high-speed bond and good gap filling without solvent toxicity problems. Because of their capacity to form a quick bond, they are favored for carton and package closing, and it is easily possible to tailor their formulation for a weaker bond for easy opening by the consumer. In some instances, hot melts may be used to provide a temporary bond to secure substrates for other bonding methods, or for temporary positioning bonds for stacked cartons and positioned assemblies.

Hot Melt Blends and Additives

Hot melts may be composed of many types of thermoplastic materials (and there are a few thermoset compounds as well, although they are typically used in non-packaging engineering applications). Polyethylene, EVA, acrylates, and many other compounds can be used depending

on the desired properties of the adhesives. Waxes are typically added as extenders, and tack agents, which are often specialized phenolic, polyterpene, rosin, or other compounds, are meant to increase the initial hot bond of the adhesive.

Because of the heat used to liquefy and handle hot melt adhesives, and the usual practice of adding new adhesive to heated storage tanks, which dilutes but does not remove older materials, problems with polymer oxidation are a concern. Antioxidants are a means of preventing the viscosity changes, charring and discoloration, *skinning*, and loss of adhesion that may occur with long exposure to heat and oxygen in production settings.

Cold-Seal Adhesives

Cold-seal adhesives have gained both in popularity and breadth of application, and have replaced heat sealing in many applications. Most cold-seal adhesives are formulated to seal only to themselves (or a treated compatible surface), which is different than a simple pressure adhesive tape-type adhesive, and may provide for accurate bond formation and tamper evidence. Because of the nearly instant seal time (0.5 seconds, compared with several seconds for a heat seal), cold-seal adhesives dominate many sectors of the confectionary, snack, and bakery market by allowing filling machinery to run almost without consideration of bond formation time [5].

Cold-seal adhesives are usually a mix of an elastomers, natural rubber or synthetic elastomers (SBR and similar compounds), and an adhesive component, often vinyl acetate or acrylic compounds. A typical formulation may be made of 60% natural rubber latex with potassium hydroxide solution and zinc diethylcarbamate [6]. Improper formulation of adhesives may result in *blocking* – the tendency of the adhesive to randomly glue the base material together before being pressed together at the seal area. The glass transition temperatures of cold-seal and self-adhesive materials may be a consideration as well, particularly with products that are going to be subjected to low-temperature treatment, exposure, or storage. If the adhesive becomes brittle, it may fracture and cause a loss of adhesion, which can cause packages to open or tags to be lost.

Failure of Adhesives, Inks, and Coatings

Although this section is explicitly concerned with the failure of adhesives used in packaging, the same principles apply to laminations, printing inks, and coatings, all of which must adhere to one or more surfaces and will suffer similar types of failures. When considering a bond or lamination that has failed or never formed properly, it is useful to consider the underlying structure of a glued joint. In all cases, a coating or ink must bond to at least one surface, and a glue or adhesive is an intermediate layer that is used to bond two surfaces together. To accomplish this, it is necessary that the glue adhere both to the surface of each material and to maintain integrity so that it does not fragment or fracture. Failure of adhesives can be broadly grouped into two categories: adhesive and cohesive failure (Figure 5.2). Inks and coatings failures are usually adhesive failures because cohesive failure may result in surface crazing but little loss of the material. Adhesive failure, as its name suggests, is a failure to adhere to one or both surfaces, and is characterized by ink, glue, or coating remaining on one or the other surface or, in rare cases, coming loose in sheets or flakes. In simple terms, the glue bonds to itself preferentially over the surface that has failed to be attached. Cohesive failure occurs when internal strength of the adhesive is less than the strength of the bonds to the surfaces of the joined materials, and is characterized by adhesive sticking to both surfaces and occasionally crumbling into flakes or crystals as well.

The most common forms of adhesive failures stem from surface incompatibility or contamination, improper application methods, or an insufficient hold time before the bond is placed under stress, and hot melt glue joints may fail from improper dispersion or wetting of the surfaces. Cohesive failure may be more complex because the mode of glue bond formation differs among glue types, but most often points to either a quality or formulation problem with the adhesive, or curing conditions that promote a weak internal structure in the adhesive layer, such as temperature or humidity extremes.

Other Bonding Agents

Tapes

Tapes have become an increasingly important part of the industrial engineering world, as improvements in fabrication have produced tapes that are effective for both bonding and shielding in a wide variety of applications. The type of adhesive used divides the tape into two general categories: pressure-sensitive adhesive (PSA) tapes and non-pressure-sensitive tapes that are usually fabricated with a water-activated adhesive. Nearly all tapes are fabricated as wide rolls of material that is then sliced to the desired width during production.

Pressure-Sensitive Tapes

Pressure sensitive tapes may take many forms, from ultra-thin varieties for optical fabrication to thick foams for joining irregular surfaces, and are available in an enormous range of capabilities for more general manufacturing and repair. They are usually fabricated with a four-layer composition: a backing or substrate material, a primer coat to assist the adhesive in adhering to

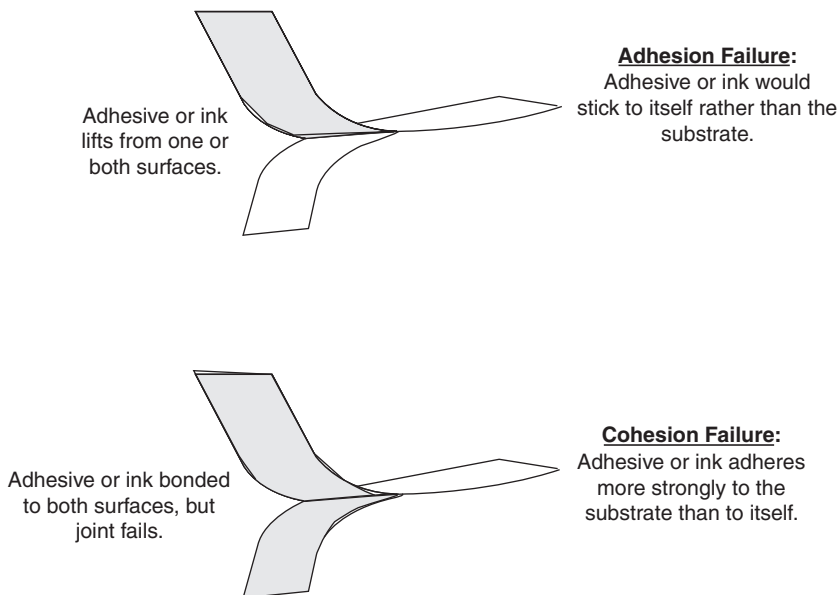


Figure 5.2. Adhesion and Cohesion Failures

the backing, and the adhesive layer itself. The fourth layer may be a release layer on the back of the tape so that the adhesive will not stick to the backing as the tape is spooled up, or it may be a separate release strip that is coated with a release layer that must be removed for the tape to be used. The adhesive layer may be made of many compounds, but historically has been made of dissolved rubber compounds, and more recently the use of acrylic and styrene modifiers as well as tack agents has increased. These newer adhesive systems have found application in cold-seal packages, discussed previously in this chapter, as well as tapes.

Tape Backing Types

Tapes are fabricated of nearly any flexible material that will accept an adhesive. Metal foils, glass fiber strands, cloth, paper, plastic film, and even wood veneers can be formed into tapes for specialized applications. Most packaging applications utilize a single or multiply plastic film, often with a reverse printing security label that indicates if the tape has been torn or tampered with. Although paper tapes continue to be produced, they have been rapidly replaced with plastic film backings because of ease of use and higher tensile strength.

Gummed Tapes

Gummed tapes have been available for as long as paper strips and water-activated glues have been available, but paper tapes with a dry glue layer date back to the early 1900s and still have uses because of their simplicity, ease of recycling, and low cost. The predominant disadvantage is that they will not stick well, if at all, to a hydrophobic surface and take a relatively long time to bond to a surface. This prevents use on most plastic packaging and many high-speed applications.

Solvent, Spin, and Friction and Ultrasonic Welding

Plastic welding includes several methods that may be used in the packaging industry to join packaging assemblies, particularly for specialized applications such as dispenser manufacture or the manufacture of unusual package types. Many of these offer a limited means of joining dissimilar polymer substrates as well. Solvent welding is the simple use of solvents to dissolve materials at their mating surfaces so that they may be joined. This method of fabrication has fallen into disuse because of problems with solvent VOC exposure both to the product and in the production facility, and long setting times, but may have specialty applications if proper ventilation and solvent-handling capabilities exist.

Spin and friction welding systems that include spin welding and vibration welding use the shear friction between two surfaces to heat and fuse structures together, providing a strong, tamper evident bond. Spin welding, a specialized version of this process, spins two circular surfaces together (such as the closure and neck of a bottle) to provide a fused joint, and can provide the method for fabricating a shell structure that could not be molded directly. Careful design of the pieces to be fabricated with correctly mating surfaces allows even relatively thin moldings to be joined into strong, appealing package designs.

Ultrasonic welding is closely related, in that it mechanically generates heat to fuse plastic materials, except that the energy is applied from a high-frequency source (usually in the 15–40 kHz range). The energy is most often directed through a contact *horn* that presses the mating plastic surfaces, and high-frequency compression then fuses the materials together.

Materials that disperse energy, such as foams or laminates with high paper content, may be hard to weld with this method, or may require the application of large amounts of power [7]. The most commonly seen use of ultrasonic welding in the packaging industry is the perimeter sealing of thermoformed packages for electronics and other high-value items. The permanent seal makes it necessary to cut the package open to remove the contents, which is intended to reduce theft (often at the expense of customer annoyance or injury).

Heat Sealing

Heat sealing using melted beeswax is one of the earliest known types of sealing, as well as one of the first tamper-evident sealing methods used for packages, documents, and liquid containers. Although waxed materials are still often sealed with heat, the development of synthetic polymers provides a more dependable material for a heat fusion joint to be used in conjunction with nearly any kind of substrate. Heat sealing can provide a permanent, hermetic seal in many types of flexible packaging, and is the preferred method for many types of films and laminates. Additionally, assembled structures such as pour spouts on pouches and complex aseptic containers are assembled with heat-sealing technology.

Heat sealing may be accomplished either by fusing the package substrate itself, as with a plastic film, or a heat seal layer or coating can be applied to a material so that the mating surfaces will fuse properly when heat is applied. There are many different types of heat-sealing machinery, but all rely on fusing either the substrate or a heat seal coating to join mating surfaces. The major types of thermal heat-sealing devices are hot-bar, impulse, and hot-wire sealing.

Hot-bar sealing, as its name implies, relies on a hot sealing bar, or bars, to compress and heat the layers to be fused. This has the advantage of faster heating of the material, but because the sealing jaws never cool, the surfaces cannot be held while the molten seal area solidifies.

Impulse sealing overcomes this by relying on a thin strip of electrically resistive material to heat the jaws once the materials are clamped. This allows the jaws to hold the surfaces together after the heating current has been turned off, so that the surfaces can be allowed to bond before being released. There is a disadvantage of a slower cycle time, but the trade-off is in more accurately formed joints. Hot-wire sealers rely on a thin, electrically heated wire to both seal and cut material, and are often used to form bags and pouches out of tubular film stock, as well as non-critical overwrapping. This last method is unlikely to provide a leak-proof, much less a hermetic, seal.

Another major type of heat sealing relies on internally generated heat to produce fused surfaces. These sealers may be induction, dielectric, or magnetic sealers depending on the type of materials to be joined and the application, but all use an electromagnetic field to generate heat either by induction currents in a metallic layer, heat from the excitation of a dielectric material, or a magnetic susceptor layer, respectively. These methods of heating are discussed more fully in the section on microwave susceptors and work in a similar manner, though at lower EMF frequencies. The advantage of this type of sealing is the ability to seal materials that are too thick or too susceptible to heat to use conventional methods. The most common example is the tamper-indicating seal under caps of food and household items. This is supplied pre-placed in the cap, and the seal is fused to the container mouth after the cap is applied, by means of an induction-heating chuck containing a toroidal induction antenna that causes the layer to heat.

Still other sealers pre-melt the surfaces to be joined using a variety of heat sources ranging from radiant heat to the application of hot gasses or mechanical friction, and then press the mating

surfaces together. These methods have the advantage of providing a seal where the substrate materials are too thick or insulative to permit heat sealing that relies on heat conduction.

Aerosols

Aerosols in their true form are dispersions of liquids or solids in a gas stream, and have been around since the time of cave paintings, and there were many types of aerosol devices in widespread use before the advent of the aerosol “bombs” in the 1940s, which were both manually and mechanically powered. The great advantage that modern aerosol packages have is that they are self-contained and self-powered, requiring neither an external compressor nor a great deal of pumping or effort to use. This is most often achieved by using a two-phase propellant, usually made of a relatively low vapor pressure hydrocarbon that maintains the internal pressure of the container by volatilizing liquid propellant as the pressure is reduced when product is dispensed, as shown in Figure 5.3.

These devices also depend on a precision valving and nozzle system to provide a well-controlled and usable spray or stream, and may rely on the propellant itself to provide a *co-solvency effect*, thinning an otherwise undispensible product such as a thick adhesive enough to allow it to flow freely through the dispensing system and then re-thicken upon rapid vaporization of the propellant after application.

Early aerosols often used highly volatile (high vapor pressure) materials to create internal pressure and to provide a solvent for the product, although these were often quite toxic and occasionally very hazardous. The development and understanding of chlorofluorocarbon

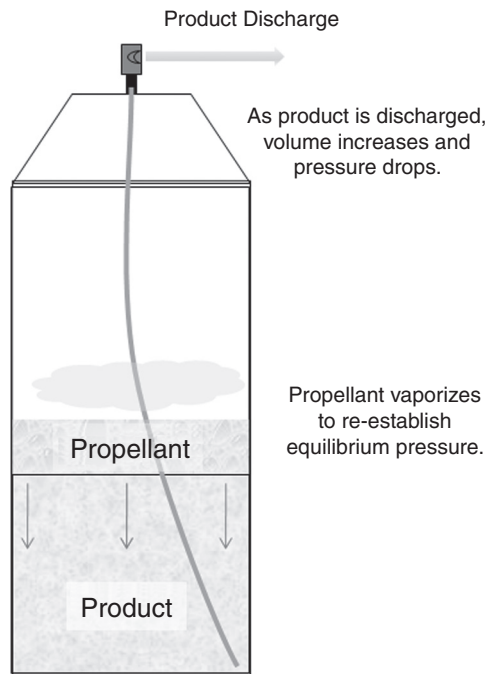


Figure 5.3. Aerosol Can Operation

(CFC) compounds that liquefied at moderate pressures allowed the development of non-toxic and non-flammable propellant alternatives that usually did not react with food, cosmetic, and pharmaceutical compounds. Subsequent discoveries about the environmental hazards of CFCs, coupled with changing market demands and their unprofitability in many markets, led to the implementation of a CFC ban in many countries [8]. Several exceptions were allowed for this ban, the most notable being for Metered Dose Inhaler (MDI) for use by sufferers from asthma and other respiratory conditions. Since CFCs are non-toxic and were able to disperse the 2–5 μm particles of medical aerosols properly into the lungs, they were retained after the initial ban. These were banned at the end of 2008, and substitutes based on hydrofluorinated alkanes (chiefly trifluoromonofluoroethane and heptafluoropropane) have been developed, although dispersant and dosage formulations had to be adjusted [9].

Aerosols can be generally classified into general classifications of miscible, immiscible, separated, and alternative propellant systems.

Miscible Systems

Miscible systems are formulated so that the propellant dissolves into the product and volatilizes out of the product during dispensing. This can be assisted by a chemical emulsifier. These systems allow the creation of foams and fine sprays that are dispersed by the expanding propellant, as well as the dispensing of highly viscous materials that require the thinning (co-solvency) effects of the liquid hydrocarbon propellant to be properly utilized. Paints, hair spray, and similar thick coatings may be dispensed through a relatively fine nozzle utilizing this principle.

Immiscible Systems

Immiscible systems, as the name implies, do not exhibit mixing between the propellant and product, which makes it ideal for dispensing streams of product rather than mists or foam, although a moderate degree of dispersion can be achieved with some products with careful design of the nozzle assembly.

Separated Systems

Separated systems have a physical barrier between the propellant and the product and are necessary where reaction with the product or any foaming or dispersion would detract from the product. Physical separation is usually achieved by use of a sliding piston or compressible bag that allows the application of pressure without mixing of the product. These types of systems are most often used with cosmetic gels and creams and other materials such as decorative cake frosting and cheese products.

Multicomponent (2K) Systems

Multicomponent (2K) systems are available for products that must be mixed before use, generally for reactive components such as polyurethane paints, epoxy adhesives, and the like. The container has one or several of the components in frangible internal containers. When the user shakes the container, the agitator ball or the containers themselves will cause breakage, beginning the reaction. The disadvantage to these types of systems is that the product must be used or discarded once the reaction has begun.

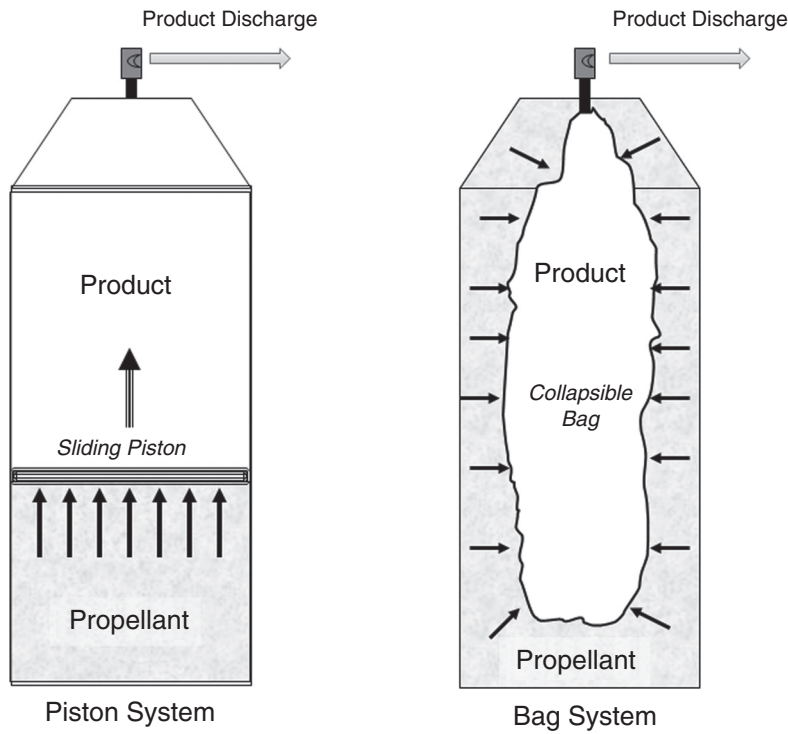


Figure 5.4. Bag- and Piston-Type Aerosol Systems

Alternative Propellant Systems

Alternative propellant systems have been developed at various points and have been intermittently used for products, often in an effort to project an environmentally friendly market image. These usually involve mechanical storage of energy via a rubber enclosure around a flexible bag containing product, or a spring-and-piston arrangement, and are roughly equivalent in effectiveness to manually operated pump spray and dispenser nozzles. Although these have been refined to work reasonably well with some household and cosmetic products, they often do not provide the substantial and consistent pressure required for many aerosol applications, and cannot provide co-solvency for viscous products and may be difficult to recycle.

Air-Powered and Compressed Gas (Single Phase) Aerosols

Air-powered aerosols are extensions of the hand-pumped dispensers mentioned elsewhere in this chapter. These rely on manual operation of an air pump to provide and maintain pressure to the container, and offer the advantages of being available in unpressurized form and using a relatively inert propellant. This allows the customer to add product, then dispense it in aerosol form, and is often used by cosmeticians and for small area applications of pesticides, medical, and paint products. Although these types of aerosols do not maintain pressure at a particularly accurate level, they may be adequate for some types of applications.

Compressed gas (single phase) aerosols rely on simple pressurization of the aerosol container to dispense and disperse product. Although this offers the advantage of using inert propellants

such as nitrogen, nitrous oxide, or helium for specialty applications, the pressure will drop in proportion to the expanding volume in keeping with Boyle's Law, $PV = k$, which states that the pressure times the volume will be constant. Thus, as the product is used and the internal volume increases, the dispensing pressure will drop proportionally, which may affect operation of the aerosol. Although this could be circumvented by the use of a pressure regulator in the valve assembly, no manufacturers currently produce such an item. These gasses are used most often because of their lack of affect on the product. Nitrogen, inherently non-flammable and quite insoluble, may be used with products that are combustible or require pressure without additional foaming action (such as some European beers), and nitrous oxide is often used with whipped cream and other food items because of its high solubility that provides good foaming action, and lack of off-flavor production.

Propellant Types

With the banning of CFC compounds by the Montreal Protocol, many aerosols have resorted to using combinations of hydrocarbon gasses, either HCFC compounds (which themselves will be banned by 2030) or propane and butane blends and variants [10]. Careful selection of the composition of the propellant as well as the mechanical components of the aerosol dispenser will allow the tailoring of pressure characteristics to suit the application. From Table 5.1, one can see that hydrocarbon propellants can be blended to provide nearly any intermediate vapor pressure desired at a particular temperature, and are designated by a letter followed by the pressure at 70°F (21.1°C). Thus, a -50 suffix propellant will provide 50 psig (345 kPa). The letter designation helps describe the mix of ingredients that provides the pressure, and these can overlap considerably because most of these refer to a combination of Propane, Isobutane, and n-Butane. These may be selected for various reasons, and different mixes can provide density and solubility characteristics to match the product and dispensation requirements.

Aerosol Hazards

Aerosol dispensers are unique in that they are one of the few types of packages that may become hazardous regardless of the product they contain. There are many instances of damage or

Table 5.1. Properties of Aerosol Propellants

Propellant Properties. Pressures in psig, (kPa) at STP				
Type	Inert Gasses	Hydrocarbons	Fluorocarbons	Ethers
Compounds	CO ₂ , N ₂ , NO	LPG: (Propane, Isobutane, n-Butane mixes), Isopentane, n-Pentane	1,1 Difluorethane (HFC152a), 1,1,1,2 Tetrafluorethane (HFC134a)	Dimethyl Ether
Vapor Pressure at 70°F (21.1°C)	N/A	Propane: 108.0 (744) Isobutane: 31.1 (214) N-butane: 16.9 (117) Isopentane: -3.1 (-21) N-Pentane: -6.2 (-43)	152a: 63 (434) 134a: 71 (490)	63 (434)

injury caused by aerosols being overheated, punctured, or corroded, and all aerosol containers are pressure-tested at levels equivalent to those found at 50°C (121°F) before filling, and cans are tested for leaks or failure by immersion after filling and capping in hot water in the production facility. Although the U.S. Regulations (CFR49§178.33) have been amended to no longer specifically require water bath testing, other regulations on the transport of dangerous goods may still require it, particularly in European countries [11]. There is some objection to this testing based on problems with aluminum and polymeric containers being degraded by the water bath, but alternate test methods have been proposed, and several that are based on gas-leak sampling are available [12].

Because the ban on CFC propellant has driven a trend toward using combustible hydrocarbon propellants, there are instances of cans, particularly those that corrode from storage for long periods in damp environments, leaking combustible gasses and causing catastrophic fires and explosions.

Flashback tests, which indicate the degree of flammability hazard, are based on whether a projected aerosol stream will ignite, if it will create a *flame projection* (ignition of the aerosol stream), as well if there is any kind of *flashback* – flame projection that extends back to the aerosol container at any degree of valve opening (Figure 5.2).

The flame extension test is conducted by holding the aerosol can 6 inches from a flame and discharging the product across the flame. The extension of any flame from the flame source (typically a candle) in inches is noted and recorded. Any flame extension more than 18 inches or any flashback of flame to the valve at any degree of valve opening would then dictate the proper labeling of the product as either being flammable or extremely flammable. Flashback occurs when the flame is drawn back toward the aerosol can by the stream of propellant. This would indicate an extremely flammable product. [13]

Aerosols (as well as other products) must also be labeled according to flammability:

16 CFR 1500.3(c)(6) defines the terms “extremely flammable,” “flammable,” and “combustible” as extremely flammable if, when tested, it has a flash point at or below 20° Fahrenheit (F), flammable if it has a flash point above 20°F and below 100°F, or combustible if it has a flash point at or above 100°F up to and including 150°F. [14]

Nozzle Design

The success of an aerosol package depends on the careful matching of product, propellant, valve, and nozzle assembly. Typical nozzle assemblies consist of a valve and container neck unit that is crimped after filling and is supplied with a nozzle that is carefully matched to the product and application at hand. Additionally, a *dip tube* may be used to carry the product from the can into the valve assembly, and these may be weighted to allow spraying at any angle, although this is not common. Products such as pavement-marking paint and whipped cream, which are intended to be used with the can inverted, do not require a dip tube.

Microwave Packaging

Microwave heating, described more fully in Chapter 2, has been an increasingly ubiquitous feature of life – microwave ovens are currently in use in nearly all households and many commercial and institutional kitchens. Packaging materials were not a component of microwave

Table 5.2. U.S. EPA Flammability Statements for Aerosols

Criteria	Required Text
Pressurized Containers	
Flash point at or below 20°F, or if there is a flashback at any valve opening, or if the flame extension is greater than 18 inches long with flashback.	Extremely flammable. Contents under pressure. Keep away from fire, sparks, and heated surfaces. Do not puncture or incinerate container. Exposure to temperatures above 130°F may cause bursting.
Flash point above 20°F and not over 80°F, or if the flame extension is greater than 18 inches long	Flammable. Contents under pressure. Keep away from heat, sparks, and open flame. Do not puncture or incinerate container. Exposure to temperatures above 130°F may cause bursting.
All other pressurized containers	Contents under pressure. Do not use or store near heat or open flame. Do not puncture or incinerate container. Exposure to temperatures above 130°F may cause bursting
Non-pressurized Containers	
Flash point at or below 20°F	Extremely flammable. Keep away from fire, sparks, and heated surfaces.
Flash point greater than 20°F and not over 80°F	Flammable. Keep away from heat and open flame.
Flash point greater than 80°F and not over 150°F	Combustible. Do not use or store near heat or open flame.

[40 CFR 156.78]

Source: United States Environmental Protection Agency (2007), "Label Review Manual Chapter 9 – Physical or Chemical Hazards, September 2007." Op Cit.

heating of foods at the outset of home microwave use. As frozen and refrigerated foods of all types were marketed to meet the increasing demand for ease of preparation in microwave ovens, the use of packaging materials to manage the heating process – and in some instances provide functions such as surface browning that microwave ovens (which do not produce radiant heat) lack – has increased as well.

Because microwave ovens convert electromagnetic energy to heat throughout the body of the product, without the usual heat transfer mechanisms to provide traditional textures and coloring to surfaces, many products were originally thought bland, doughy, or otherwise unpalatable. Much work has been done to provide comparable surface browning and crisping both through product formulations that have high levels of surface sugars and fats as well as packaging materials that are highly lossy and create high temperatures at the surfaces of the foods to provide browning or crisping effects. One of the most widely adopted components in food packaging over the last two decades has been the addition of a microwave *susceptor* to facilitate convenient and effective product heating in microwave ovens. The most commonly seen version of this is with microwave popcorn, which uses a susceptor to melt and heat the fats used to cook popcorn so that the microwave field does not simply incinerate the popcorn. Other common usages are for baked products and pizza, where consumers have learned to expect browning and hard crust formation. Most of these exploit some aspect of induction heating or magnetic oscillation to generate heat from the microwave field, though there are a few that may depend on heating processes that more closely mimic the foods themselves.

Microwave Heating and Interaction with Packaging Materials

The simplest classifications of packaging materials are for “traditional” types of containers: metal that is reflective or opaque to microwaves, and glass and paper that are effectively transparent to them. Despite the folklore that exists regarding the reflection of microwaves back into the magnetron by metallic containers or foil causing violent failure of the oven, little harm is done to microwave ovens by metallic containers, and modern magnetrons are made of ceramic and have thermal cutouts to protect them. Because early magnetron tubes were made of glass, excessive waveform reflection back into the magnetron tube could cause it to overheat and fail, giving rise to the myth that putting metal objects in a microwave oven will cause it to fail or even explode. Given that microwave oven cavities have metal walls, and occasionally metal racks as standard features, this does not make a great deal of sense. Modern microwave ovens have magnetrons that are based on high-temperature ceramics and are protected with thermal shutdown devices to protect them from overheating, so putting metal objects into a microwave is unlikely to cause the problems that the urban legend describes.

Microwave ovens and heaters generate heat by creating a strong electromagnetic field (EMF) near a material that causes molecular agitation and therefore heating. Given that the electric field and the magnetic field operate in opposition to one another in order to satisfy the conservation of energy, there are several heating modes (electric field, magnetic field, and bimodal) available to heat foods. In most food products, the most common mode of heating is caused by polar molecules rotating to try and align themselves with a rapidly alternating electric field, and causing heat from molecular excitation. The most efficient heating in most household microwave ovens will be the result of interactions with water, with decreasing heating rate with fats and sugars as they are less polar. Because the microwave energy that is being applied to the materials to be heated are being absorbed and converted to heat, they are termed lossy materials. Similar technologies are used for stealth coatings on ships and aircraft, relying on absorption by particulate carbon or iron rather than complex food compounds. However, the EMF will generate induction currents in the metal, causing it to heat and generate enough voltage to cause sparking, which may frighten consumers or cause fires or interior damage in the oven cavity. On a much smaller scale, this is exploited in many types of susceptors that utilize metallic inks, fragments, or coatings to generate limited-surface heating. As microwave ovens became popular, it was clear that the traditional foil trays used for frozen foods would have to be replaced because they blocked much of the EMF and caused slow and uneven heating. Early replacements were constructed of coated paper, and subsequently thermoformed plastic trays have come to dominate the industry.

Glass is transparent to microwaves if it does not have a significant metallic component (as many other ceramics do), and is ideal for heating foods apart from its usual limitations of fragility, cost, and weight. Because of this, heating foods in their glass jars or bottles is often suggested by the manufacturer. One of the peculiar hazards of this is flash boiling, where the lid is not loosened to vent excess pressure during heating and either explodes messily in the oven or boils explosively when finally opened by the consumer, often causing severe burns.

Most plastic materials as well as paper are transparent to microwave energy and are well suited to heating frozen and fresh foods. The exceptions are melamine-formaldehyde thermoset resins that will heat and fracture quickly in a microwave field. These resins found their large market in tableware during the 1950s and 1960s, and can still be used for screw-caps in the packaging industry, but are infrequently seen in modern consumer goods, partially due to the unsuitability for microwave use. Additionally, paper or plastic with metallic inks or coatings can

arc and heat in an EMF field, which should be considered when designing graphics, labeling, and printing.

Types of Susceptors

Susceptor heating predates microwave heating equipment because it has been used at frequencies ranging from very low frequency AC current to radio frequencies on various sorts of induction furnaces, heat-treating apparatus, and chemical processes. The original microwave susceptors were carbon-particle or metallic inclusions in paint used first on military ships and aircraft in an attempt to defeat radar reflections by converting the incoming radar pulse's electrical component to heat; many of these are still based on ferrous compounds and particles. For the applications typically seen in consumer packaging, the single frequency and relatively high power concentration (and lack of concern about reflection) provide a different set of performance criteria.

Susceptor Formulation

Most common susceptors exploit the shifting magnetic field component of the EMF to generate induction currents in a resistive material, which then are converted to heat. Because metallic objects will produce high-voltage fields and arcing in the microwave field, the object of this is to provide enough current to generate high heat without causing arcing or fire. There are other types of susceptors that utilize the shifting electric field to generate heat in a saline solution, and these offer the benefit of reducing their heating effect as the water is boiled out of solution, but these are not commonly used.

It is possible to construct many sorts of susceptors, but very few of these have seen widespread commercial production, often for reasons of cost, speed of production, or variability in use. By far the most common type of susceptor is constructed from metalized film, either as a patch or as a pattern produced by selective metallization on film. This then produces thermal energy that is transmitted to the product either by conduction in order to firm and brown the product (such as pizza crust), or by infrared radiation to provide a crisp, brown surface, as is done with browning sleeves for pastry products. Similar results may be obtained by coating or printing a surface with metallic inks, although there have been problems with these fragmenting as they heat. The actual mechanism of heating results from the metallic coating or material converting an EMF's magnetic field flux to electrical current (hence, the sparking of metallic labels), and this current then inducing resistance heating, with the thickness and composition of the heating layer affecting the overall impedance and heating efficiency, with a theoretical best square resistivity value of approximately $188.5 \Omega/\text{sq}$. [15]. It is also possible to construct films or coatings that fragment in use, limiting heating, but this is not often done because of the unpredictability of oven type and consumer usage.

Other possibilities include susceptors that may absorb oils or moisture from the food, and may alter their heat generation as these components are sorbed and desorbed from the susceptor. These are seldom used because of the need for very high heat levels for browning and crisping. It is also possible to combine thin film and thick organic coatings to more efficiently utilize both electric and magnetic field components, but this is seldom done with consumer food products for reasons of cost, complexity, and concern with contamination with the coatings.

Patterned Susceptors and Reflectors

Because the wavelength of 2,450 MHz microwave ovens is predictable at 12.24 cm, it is possible to create diffraction patterns by selective metallization of the susceptor, as described in Chapter 4, that act as lenses or shields to concentrate or deflect energy on certain parts of the product by creating artificial nodes, antinodes, or reflecting part of the power input. Although the principles of EMF diffraction have been established for some time in microwave communications and radar applications, the implementation was only explored in microwave cooking after sufficient market penetration occurred to create very large markets for microwaveable foods. Unfortunately, some of these implementations can suffer from the variability of oven types and power, and so they have only been seen on a few specialty products.

Heating Effects and Toxicological Concerns

Recent work has been concerned with the production of unwanted chemical species, either as otherwise entrained materials liberated from polymer structures or as created as pyrolysis or other thermal decomposition by-products under the extremely high temperatures found in some susceptors. It is also of some concern that the very high heats generated in the susceptors may be leading to the thermal decomposition of the polymer film, paper backing, or adhesive used in many food products' susceptors, but there is no currently available definitive data about this potential problem.

For surface temperatures to be hot enough to brown food, point temperatures in the susceptor structure have to be high enough to generate heat in the susceptor material, transmit it to the surface, and then, depending on the product, conduct or radiate the energy to the product. Inspection of a popcorn bag or a pizza tray after use will show distinct browning of the paper fibers, indicating very high temperature generation. Studies have shown that susceptors that achieve 100°C in the product may show internal susceptor temperatures of approximately 200°C [16]. These temperatures can create situations where compounds are liberated into the product, and studies have shown that the susceptors themselves degrade with use [17].

Other studies have shown an increased rate of compounds released over time, ranging from bisphenol-A and volatile organic compounds to fluorocarbons during microwave heating [18–20]. Additionally, there is evidence of microwave energy liberating residual antimony from the original PET polycondensation catalyst process as a result of microwave heating [21].

Both the level of exposure and often the long-term health effects of these indirect food additives are unknown to a certain extent, and because of the extreme variability of exposure conditions, this remains somewhat controversial. The United States Food and Drug Administration has issued a Guidance for Industry document describing test protocols, recommendations, and requirements for materials producers, but these are very limited and are often non-binding. EEU protocols are similarly non-specific, and research is ongoing [22, 23]

Printing and Coding Processes

Printing, marking, identification, and decoration of goods and possessions is one of the oldest processes known. Few if any packages are intentionally shipped without markings of some kind to at least identify the contents, and all consumer products take advantage of the package to identify, market, and comply with labeling requirements.

Traditionally, printing has implied a great deal of setup and a large number of identical items being produced, whereas coding is more closely associated with changeable information such as lot numbers and freshness dates. As printing processes evolve, this distinction is beginning to blur, with digital presses gaining in speed to rival moderate-speed fixed-copy presses, and with the ability to print different copy on each label, carton blank, or tag.

Additionally, the usual model of applying ink to a paper or polymer substrate is changing with the ability to apply adhesive, hot-stamped, microembossed holograms or other decorative graphics, as well as technical devices such as programmable RFID tags.

History

The history of printing is inextricably intertwined with human history, with hand-copied texts, cave paintings, and various palimpsests giving us our view into antiquity. Various forms of mass-printing have been developed, using slate slabs (lithography), carved type and illustrations (letterset), and early engraving-based printing schemes (intaglio). Security seals have been formed of wax or clay, and embossed with unique, carved signet seals, giving us the term “signature” as a description of a unique identifier.

Types of Printing Processes

Traditional printing processes have usually been concerned with transferring a liquid ink from a reservoir to a substrate material in a predetermined pattern. This may be as simple as a rubber stamp or as complex as the precision multicolor presses that are used to print banknotes, stamps, and magazines. To give some order to the vast number of processes and systems available, it is helpful to dissect them into several broad categories: direct and offset printing; and subsurface, planar, and relief printing types.

Direct and Offset Printing

As the name implies, direct printing applies ink directly to the substrate surface. This has the advantage of ensuring precise placement of the image without an intermediate step, but can be unsuitable for irregular surfaces and may wear the printing plate surface down quickly. Offset printing applies the image to an intermediate material, which then prints the image onto the substrate. While this can increase the difficulty of accurate image registration, it also allows the printing process to be tailored to the specific material to be printed, and can reduce wear of the printing plate. Offset printing is almost always used in conjunction with lithographic or letterset printing, although it is possible to use the principle with other methods.

Subsurface Printing

Subsurface printing is almost always done using a gravure method, which is the commercial form of artists’ intaglio printing (in which a smooth plate is carved with an image composed of continuous lines or patterns). Traditional intaglio processes can still be used for high-value items such as banknotes and stamps, but more usually this is a gravure process where the plates are fabricated under intense pressure from a handmade master intaglio design. Gravure (using flat plates) and rotogravure (using engraved cylinders) processes produce high-quality impressions over long production runs by using a regular pattern of *wells* (microscopic indentations) with varying depth as the design requires. Rotogravure printing uses etched ceramic or metal rolls

that may be mechanically or laser etched. Mechanical etching produces diamond-shaped wells, whereas laser etching produces rounded wells as the cylinder material is ablated. For either method, once the plate or cylinder is etched, the printing process is one of applying ink to the entire printing surface, scraping off the excess surface ink with a flat *doctor blade* that removes the surface coating, and then impressing the remaining ink that is trapped in the etched design to the substrate, usually under a good deal of pressure. The setup expense for a gravure process is very high, but the durability of the rollers and the accuracy of reproduction often justify its use for very long production runs.

Surface Printing

Lithographic (*lat.* “stone writing”) surface printing is historically based on the mutual repulsion of water and oil. In its original form, artist’s prints were produced by drawing the original design on a slate with wax. The flat sheets of slate were hydrophilic, whereas the wax was hydrophobic. When wetted with water (which would stick to the bare slate), then with oil-based inks (that would not stick to the water film but would adhere to the wax pattern), the ink would remain in “dry,” waxed design areas, allowing the image to be reproduced. While still used in fine-arts applications, this method has obvious commercial limitations, but the practice has been expanded, using the same principles, to chemically coated plates and then to the photopolymer plates currently in use.

Surface printing plates are typically sheets treated with a water-repellent polymer that is photopolymerized, often in a laser-scanning device similar to a laser printer that reproduces artwork directly to the printing plate from digital graphics files. The ink transfer area is then retained while the rest of the surface is dissolved away. This leaves a water-repellent transfer area with the required design on a substrate support material. Some advances in method have been developed, including selective irradiation of ceramic surfaces to provide transition from oleophilic to hydrophilic surfaces and back again, but the photopolymeric plate fabrication remains a favorite [24].

Raised Printing

Raised printing depends on ink applied from the raised surface of an image, requiring that the printing plate or roller be constructed in such a way to provide a clear, distinct image. Traditional letterpress methods have relied on cast metal (usually lead) type and images, but have given way to polymeric printing plates and other methods that are less hazardous and more cost- and time-efficient. Raised printing can be made of a range of materials, from metals to rubber, depending on the application. Direct printing is most often done using high-relief letterpress methods, whereas letterset printing uses low-relief printing surfaces in an offset printing process. For direct printing, the processes use reversed images and raised type to transfer ink onto substrate. The plates or rollers are made of metal or polymer, depending on the application. Although letterpress would be an ideal application for a durable ceramic photopolymer, little work has been done in this type of application.

Letterpress plate fabrication is done using a negative image or optical scanner to polymerize low-relief images on the surface in a manner similar to the offset lithographic plates that the technology was derived from. The low-relief plate readily prints to offset blanket in a manner similar to offset lithography, except that the printing plate’s surface relief is used to print to the offset blanket rather than oil-water interactions, resulting in it being termed *Dry Offset*.

Flexographic printing, which uses a flexible polymer printing plate, may be used in either direct printing or offset printing, depending on the application. Plates are inexpensive but not

as durable as metal letterpress, and are manufactured in a manner very similar to those used in photopolymer letterpress. Cushioning is provided by flexible type and a cushioning layer on the plate cylinder, and the flexible printing surfaces allow the artwork to be transferred to irregular surfaces easily. Because of this, it is the preferred method for printing corrugated board and other very rough surfaces. In flexographic methods, a textured *anilox* roller transfers ink to flexible surface in a manner similar to inking a rubber stamp. The anilox is usually engraved to hold ink, and any excess is removed with a *doctor blade* before inking the printing plate cylinder. Letterpress printing is a common and popular method with packaging because of increasingly good graphics that can be applied to a wide range of surfaces and materials, as well as low costs.

Color Theory and Multicolor Printing

Current printing processes rely on applying several colors in overlapping layers and density to generate intermediate tones and colors. Whereas video displays and most inkjet and laser color printers rely on a standard set of colors (usually RGB or CMYK), printers may use many nonstandard colors to provide the desired effect. The preparation of color plates and cylinders used to be based on very large photographic cameras fitted with specific color filters, but with the broad implementation of digital graphics, color separation can be done directly from the image. The output can then be used to directly generate printing plates or rollers for each color, and will allow for the digital transmission of print job information to many locations via data file.

To better understand how multicolor printing operations can create a full spectrum of colors from a very few basic monochromatic inks, it is necessary to mention some concepts of color addition and subtraction. Color addition and subtraction, so called because addition contributes to make white while subtraction reduces from a basic white state, are commonly used in many items, from printing to display screens of all types and even indicator LED's where red and green are quickly alternated to make yellow.

The basic principle of color addition is that adding basic colors together will produce any intermediate tone required. These are usually RGB – Red, Green, and Blue – in video displays. Printing and photography often use color subtraction, often termed CMYK – Cyan, Magenta, Yellow, and Key (black) – which is often applied in that order during the printing process. Deciphering the combinations can be done with a little real-world experimentation, yielding the following combinations (Table 5.3).

Whereas the overlapping colors of color addition can be somewhat intuitive, understanding color subtraction can be a little more confusing. One way to consider it is to think of the colors as being filters that only allow their particular colors through. Thus, white light “subtracting” magenta transmits only red and blue while blocking green, and cyan, which transmits only blue and green, blocking red, further filters the light, only transmitting the color in common between the two – blue. The practical implications of this are more complex, and are part of the art and

Table 5.3. Color Addition and Subtraction Table

Color Addition	Color Subtraction
Red + Blue = Magenta	White – Yellow & Cyan = Green
Red + Green = Yellow	White – Magenta & Cyan = Blue
Blue + Green = Cyan	White – Yellow & Magenta = Red
R + B + G = White	White – C, M, Y = Black (K)

technology of commercial printing. For example, a transparent blue ink (that only transmits blue light) laid over a yellow substrate (that only reflects red and green combined, while absorbing blue) will not have any light of the proper tone to transmit, appearing black rather than the expected green.

Colors may react to light depending on frequencies absorbed. Red absorbs the high-energy end of the white light spectrum, which often results in the fading of red printing and paints before any other color. For this reason, red pigments are more difficult and expensive to use. Different light sources have different spectra, often described as a *color temperature* relating back to tungsten filament bulbs, with high color temperatures being blue-rich and cooler ones being richer in the yellow and orange spectra. Each temperature will provide different appearances to an item, so printing jobs must be run with the final viewing light in mind, and printing operations may have different light sources for evaluating final copy (Table 5.4). For example, a cosmetics boutique brightly lit with halogen lamps will probably have a different product appearance than in a large discount retailer lit with cool blue fluorescent tubes, even though the product may be the same.

Color Standards

To allow colors to be communicated and included in specifications, sets of color standards are produced with coding systems to give uniformity to printing operations when blending inks. Typically, a set of color standards is printed and circulated that the press operator will use to match a blended patch of ink on the relevant substrate, literally a spot check. In the United States, commercial sources such as E. G. Pantone® color swatches are used, with other similar sources available worldwide. The use of common standards then maintains colors and printing schemes among printing plants and across a series of production runs to ensure that a particular color scheme is maintained accurately. Increasing integration of printing from computer monitor to press run has introduced complications in color matching and has made the calibration of monitors and accurate color continuity an ongoing technical concern in the design and printing industries. As the printing industry changes to digital distribution, the process of matching colors will expand from on-the-shelf products and advertising copy to include online content and video displays, all of which must correspond properly with the intended color schemes.

Halftones and Shading

Resolution – the ability to distinguish closely spaced objects – is limited in the unaided human eye. Printing takes advantage of this to make *halftone* shading and colors by constructing

Table 5.4. Color Temperatures

Some Examples of Color Temperature	
Typical Source	Color Temperature
Incandescent Lamp	2,700–3,300° K
High Temperature Flood Lights	3,500° K
Arc Lighting	4,100° K
Sunlight	5,500–6,000° K
CRT/LCD Screen	Usually Selectable – 9,300° K, 6,500° K and 5,000° K

fields of dots and patterns of varying diameter and density that the eye “runs together” into smooth tones. The same effect is achieved in other visual displays such as computer screens, LCD and plasma televisions, and inkjet and laser printers. Although it is nearly impossible to commercially impress ink in controlled, thin layers to provide shading, printing processes are able to precisely reproduce varying densities of individual discrete color dots of varying size and dot-density to provide shadings and tones. Halftone *screens* were used to segment colored areas for printing, but this has been given over to computer processing of the fine patterns as well, even though the terminology remains. Misalignment of the halftone screens can cause unsightly “Moiré” patterns to appear in solid colors – these are often seen in color supplement printing in newspapers.

Types of Substrates

While nearly anything can be printed or marked in some fashion, the general consideration of substrate types starts with the consideration of whether the material is fed in sheets or in web form (usually taken from large rolls), and if it is cut or rerolled after printing. Beyond that, the type of material surface (paper, polymer, foil, sheet metal, etc.) has to be considered to select the best type of printing process for the application. As previously described, flexography is a good process for small-to-medium runs (unless plate replacement is not a factor) and can provide adequate graphics reproduction, whereas the printing of exact copy on relatively smooth surfaces such as currency and stamps may require an intaglio process.

Types of Inks

Inks are typically composed of a *vehicle* (a liquid carrier component) and a coloring agent that may be a solid pigment, a liquid dye, or a combination of the two. Additionally, there may be a vast array of modifying agents such as surfactants, brightening agents, polymer resins, and the like, depending on the particular application.

The earliest printing inks, intended for use on the first presses, were a mix of black pigment (often from wood or vine charcoal or burnt bones) and oil or animal glue. The oil-based inks are remarkably similar, in principle at least, to the soy-oil-based inks used in newspapers today. They have the disadvantage of requiring time to absorb into the paper fibers, leaving the pigment on the surface. Later developments substituted volatile organic solvents in place of the oils to reduce the drying time. This is particularly important for dye-containing inks because liquid dyes can continue to travel along absorbent fibers, particularly through paper substrates, causing blurring of the copy and images. Problems with volatile organic compounds (VOC) being absorbed by food products, and workplace exposure by printing workers have driven printing inks to rely on differing polymerization processes such as ultraviolet and electron beam curing photopolymers, and other compounds that polymerize or harden with moisture loss or exposure. Polyol-based urethane resins are used as a flexible high-adhesion, low-reactivity vehicle to replace aggressive solvent systems and reduce incompatibility between ink systems that requires press downtime for cleaning [25].

Like any surface coating, the ink must be compatible with the substrate to which it is being applied, as well as any other coatings or printing on the surface. There have been instances of perplexing adhesion failure of single colors of ink on package surfaces because of a mismatch of that particular ink batch to the substrate type. Aggressive solvents may etch or dissolve the surface as well, leading to package failure, and some types of inks may contain chemicals

that alter the structure of the packaging material via sorption of organic chemicals, which can affect shelf life or other product quality factors by changing barrier characteristics. Thus careful matching (and testing) of ink-substrate compatibility, as well as consideration of other factors such as exposure to solvents such as alcohol in the product, or heat resistance during package sealing, must be made.

Printing Surface Choices

Surface printing is the simplest and most common type of printing, depositing ink directly on the exposed surface of the material. It may be subject to surface abrasion or other damage unless coated or protected during shipping and handling. Reverse printing is done on the back side of a transparent/translucent material with the copy reversed so that it appears properly through the cover material. When managing this type of printing run, the sequence of application must also be reversed to be sure that large background areas go on last. This has the advantage of providing protection from abrasion or contamination. Because the substrate is also acting as the cover, the texture and optical properties of substrate will affect the final print quality and feel. Thus the surface finish of substrate becomes critical. *Locked-in* printing is surface-printed material that is laminated under another protective layer. This allows changing of copy by changing a relatively inexpensive surface print job without having to throw out a more expensive barrier film. As with reverse printing, the surface finish is critical. Of course, combinations of these are commonly done to achieve a particular design objective.

Printing Production

Graphic Design

Graphic design (the artistic elements of which are beyond the scope of this book) is typically done in conjunction with product marketing and sales. Complex graphics cost more to develop and reproduce, so simple, clever designs can be very cost effective, although the contrary argument is that elegant printing and decoration can push the price point of a particular product up considerably. The world of advertising is full of examples of unprofitable products that have become wildly successful because of clever packaging and marketing. For unusual packages, distortion requirements may be an important factor as well. For example, pre-printing flat sheets to produce metal containers has been successfully used for shallow-draw cans, and shrink sleeves used on glass containers must have printing that will contract to provide the appearance of being printed directly on the container.

Focus groups and consumer test panels are often used to finalize designs, and test-marketing may change the designs even further in an attempt to fine-tune the graphic elements to give the greatest customer appeal.

Once the graphic design is finished, color separation is done so that presses can take the complex color artwork that broken down into basic color components used to create the individual printing plates or rollers, and allow the image to be reassembled on the packaging substrate.

Plate Making

For multicolor press processes (rather than dot matrix or color photocopying), printing plates are made for each of the component colors in the printing process.

Traditional lithography plate making was done with large cameras and photo-etching technology, but plates are now made by direct laser printing onto photopolymer plates that create a differential between hydrophobic and hydrophilic surfaces. Raised surface plates can be cast or produced by photopolymerization, and gravure plates or rollers can be produced by laser pitting, diamond stylus engraving, and chemical etching or, in rare cases, traditional mechanical etching and cutting.

Process Type Selection Criteria

Substrate

The type, composition, quality, and variability of the substrate all have an influence on the process type. Sheets of corrugated board will be handled differently than thin polymer films and metal foils, and each type of process has a useful range of operation. Flexography is well suited to irregular surfaces whereas gravure direct printing will only work with relatively smooth materials.

Number of Colors

Presses are available in any number of colors, but the cost and complexity begins to escalate with increasing numbers of layers. This can also limit the number of suppliers who can do a job if it is extremely specialized.

Quality Requirements

Even though flexographic printing has the capability of doing very precise reproduction, it is most often used for simpler, less accurate printing where the replacement of printing plates is less of an issue. The other extreme, long print runs of highly accurate images such as banknotes and security seals, can justify the high setup costs of intaglio printing.

Size of Printing Run

The length of the printing run and the application will influence the type of printing process used. Very short printing runs might use a photocopier or laser printer, whereas longer runs might use offset. Gravure is most often reserved for very large print jobs because of its high setup cost. Each process has a range of economic feasibility.

Available Equipment and Supplies

Printing process types may also be determined by other factors such as the availability of printing facilities nearby or a specific demand for a particular appearance or texture.

The Preliminary Press Run

Before committing a press facility to high speed runs and consuming enormous amounts of materials, press operators will run test batches of materials through printing (and subsequent cutting and trimming operations, if any) to determine if the copy is being positioned properly, if

color registration is correct, and if there are likely to be any significant problems in production. Preliminary runs may be used for consumer preference, marketing review, or final approval purposes as well.

Other Types of Printing

Microembossing and Holographic Films

Microembossing is the use of electroplated relief plates or rollers to create a surface pattern in the surface of a substrate, most commonly a plastic film. Foils and even paper (at larger scales) can be treated this way, although paper will not have the spectacular optical effects of other materials. With reflective or transparent materials, interference patterns can be created, which allows the creation of shifting multicolor graphics as well as static and multiplexed holographic images. Microembossing is also used in the production of cast and stamped MEMS (Micro-Electro-Mechanical Systems) dies and devices for the electronics and medical industry.

To produce microembossed films on a large scale, a traditional laser-based master hologram must be made, either from models or from optical patterns created via an LCD system. From this, a *rainbow* (white light) transmission hologram is produced in a photoresist surface, which polymerizes under the influence of the projected light patterns and is developed in an etching solution to create a raised surface that preserves the projected interference patterns. This surface is then coated with silver or other electrically conductive material, creating a *mother shim*. These are electroplated with nickel used to create electroformed *child shims*, which are peeled off, attached to rollers, and used for the actual film embossing process.

Microembossed films may be used in transmission mode for other color effects, but for the holographic image to be realized, it usually must be printed or laminated onto a reflective film so that light transmission from the rear of the image can reproduce the original pattern. Although the cost of the initial setup for these processes can be quite high, subsequent production can bring the price down significantly. Additionally, the technical complexity of creating a holographic image has provided a ready market for security seals, ID badge features, and the like, because casual counterfeiting is thought to be difficult.

Screen Printing

Screen printing, which is usually associated with the printing of designs on fabrics, is used to produce images on irregular surfaces of nearly every type. The basic principle involves pushing viscous inks, coatings, or adhesives through a mesh that is blocked to allow an image to be formed from the remaining open-meshed areas. Although artisan-level production is troublesome, and requires frequent screen cleaning, it is possible to use automated screen printing in manufacturing situations to the extent that elegant bottle decorations for wines and spirits may be done by screen printing, as are the decorations on compact disks and wooden surfaces as well as patterned adhesive and coating application for specialty processes.

Transfer Printing and Labeling

Transfer printing is a general class of printing that blurs the distinction between labeling and printing, as it usually does not rely on liquid inks or printing materials. Instead, material is *hot stamped* to the surface using a heated silicone rubber plate that adheres material to the substrate in a desired pattern via heat-activated adhesive. This is often used to transfer metalized films to

packages to create glossy and shiny images, or to supplement printing on labels and substrates. Therimage[®] is a trade name that is often used to describe a general class of labeling that resembles decal application. The label consists of a laminated paper carrier with multiprocess color labels, usually on a transparent carrier, that are transferred onto a package that has first been pre-heated by open flames to warm and oxidize the surface. A final heat treatment “cures” the inks and covering carrier film to the package.

Thermal Printing

Thermal printing can be broken down into two broad classes: thermal transfer and thermal paper-based printing. In thermal transfer printing, “ink” – actually a tinted thermoplastic film – is transferred onto surface with thermal dot-matrix print head. It has the advantages of no “drying” time and does not smudge easily, but it is slow. Print resolution is quite good, smudging is low, and the printing is well suited to optical readers. Airline operations use thermal transfer printers for tickets, boarding passes, and similar documents that require good resolution. Thermal paper-based printer uses paper containing thermally activated dyes and is commonly seen in use as credit-card slips, receipts, and on-demand labeling for delicatessens. These are good for short-term consumer use, but they are susceptible to degeneration and darkening by exposure to heat, sunlight, and organic solvents.

Ink Jet

Ink jet printers, which are commonly used as low-cost computer printers, operate by spraying microscopic ink droplets from a print head into dot-matrix pattern on surface of material, often at extremely high speeds. The print will smudge as they require a small amount of time for ink to dry or set, and high-speed resolution may be poor, though acceptable for simple alphanumeric coding. Because the printer never has to contact the printed surface, this method is well suited for very irregular items such as beverage bottles and cans during filling, building materials, and irregular bags. Additionally, very-large-scale equipment is available that achieves the same effect using pressurized ink lines and large nozzles to create large patterns, typically on shipping cases and larger packages.

Laser Debossing

Laser debossing, which is different than laser printing that deposits toner on surface, operates by using an industrial laser to burn a pattern into the surface of a material. This can work either by ablating the material or by removing ink on a specific part of the package, providing white lettering on a dark background. As laser power has increased and the debossing equipment has made the transition from simple metal pattern masks to LCD-based gating, the range of materials that can be directly marked has increased to include metals and even diamonds, and the ability to change code copy at nearly any speed is available. Although very capable, this equipment is among the most expensive because of the necessity of high-powered lasers and optical equipment.

Dot-Matrix Printing

Substrate material is printed with a ribbon/print-head system similar to dot-matrix computer printer. Because of the proliferation of inexpensive inkjet and laser printers, this method of

printing has fallen by the wayside with the exception of processes where the physical impingement of the printing head wires is useful, such as the creation of multicopy documents like invoices and receipts.

Laser Printing

Laser printing exploits the photoelectric effect to directly print an image from an optical image or laser-scanning pattern. The photoelectric effect, for which Albert Einstein won his Nobel prize in 1921, is the result of impinging photons knocking electrons from a charged surface, and is exploited in laser printers by a scanning laser causing electrostatically charged drums to pick up and reject finely powdered toner in an image, which is subsequently fused to the printed surface with a hot roller. It is well suited to applications like document printing on paper, but less so on materials that are susceptible to thermal effects. Laser printing of unsuitable plastic films can lead to printer damage. It offers extremely accurate printing with resolutions in excess of 9,600 dots per inch, but is limited in the types of material it can print.

Package Printing Versus Labeling

In the same way that different types of printing processes seek to establish larger market shares, the competition between package printing and package labeling is also an ongoing struggle for market share. A good example is the growth of clear-backed self-adhesive labels on glass bottles that replaces screen printing on glass while providing excellent graphics. The precision printing and speed of application, as well as the elimination of pre-printed inventory (which allows several products to use a standard bottle by changing the labeling) has driven this change. Labeling has the general advantage of allowing the use of a manageable inventory of standardized packages – the primary example being standardized metal cans with paper labels – with the disadvantage of having an extra step in the production process.

Many processes that assemble packages in the production line, for example a cereal-packaging line, would be poorly served by labeling operations because the outer packages themselves are little more than labels, and changeover times would not be shortened. Labeling has the advantage of providing an additional surface layer on the package to provide some degree of protection against abrasion or damage, as with glass containers. Finally, many types of labels are simple enough that they may be printed in-house, whereas the container itself (a glass bottle, for example) requires an enormous capital investment to produce, so one may be manufactured elsewhere while the label printing can be handled locally.

Coding, Scanning, and Identification Methods

Coding differs from more traditional printing in that it is used to carry changeable information, such as batch numbers, expiration dates, and formulations. More usually, a small area on the package is devoted to production information. This may be in *closed code*, encoded so that the customer cannot read it directly but still useful to production personnel and useful in the case of a product recall. Open codes are becoming more common, as well as the inclusion of “use by” and “sell by” dates on perishable products. Coding can be used to indicate variable weights, quantities, and colors on a standard package as well. The distinction between label printing and coding is becoming blurred as printing processes are developed that can generate hundreds of meters of custom text per minute, essentially allowing a different package on every product.

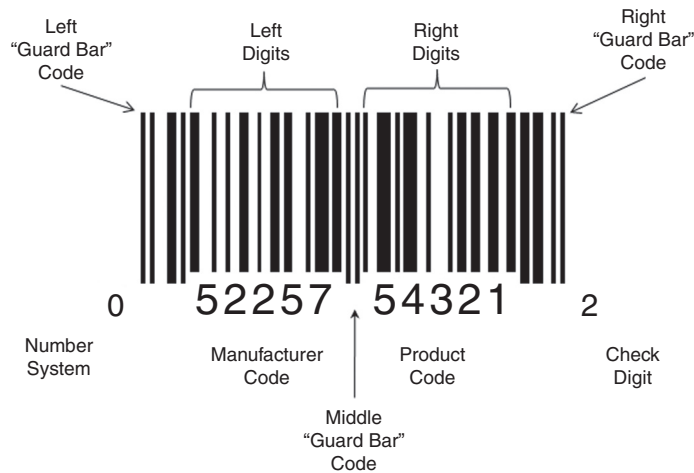


Figure 5.5. Parts of a United States Retail (UPC-A) Bar Code

Coding Methods

Coding methods range from the simplest method, such as a worker writing on a package, to the extremely sophisticated, such as laser debossing and ink jet labeling on high-speed bottling lines. In general, the idea is to mark the package with changeable data as simply, clearly, and accurately as possible. Some of the oldest automated methods are rubber stamps and automatically inked stamp wheels that use rubber type and roll along the top of the package. Similarly, embossing stamps and debossing dies (that cut or remove material rather than pushing designs into it) can be changed for a production run or day's shift, but are not as well suited for information that changes quickly. Debossed codes of all types are very common in the pharmaceutical industry and are often present on cartons and the sealed ends of squeeze tubes, though the proliferation of heat-sealed laminate tubes has required the use of dies in the heated sealing head, or second coding operations using a heated stamp.

Cut Codes

Cut coding is a simple method of coding batches of product, and is still used in the brewing and wine industries. Codes are simply slits cut down the edges of a stack of labels with a sharp blade before they are loaded into the magazines of bottling labelers. By knowing the pattern (which is sometimes explicitly printed on the edge of the label), batch, date, and other information may be read. This method has the advantage of requiring no special equipment, although the ragged edge of the label may be problematic in some labeling operations.

Machine-Readable Codes: Bar Codes and Matrices

Machine-readable codes have become the most important part of the information cycle discussed in the Chapter 1, allowing the use of networked computers to manage and track items throughout their life cycle. It allows a fast scan of product at checkout, during manufacturing and distribution, and during use. Code systems drive store inventory systems and are used for automotive applications from Vehicle Identification Number (VIN) coding to coding of license plates in

some countries. Hospital patients may have a patient code as part of their identification bracelet, and medications, devices, and procedures may be similarly coded to prevent misapplication. Because devices and products must “speak the same language,” there is a broad range of coding standards, depending on the particular application. One of the earliest and most prevalent is the Uniform Product Code (UPC) standard that is used on nearly all consumer goods, as shown in Figure 5.5, and other standard, have evolved for different application, including two-dimensional data matrix coding that can store a much larger amount of data in a small area, and is used in applications such as package delivery services and order tracking.

Another basic consideration in printing bar codes is that in all bar codes, optical contrast must be maintained for them to remain machine-readable. A black line on a blue ink background will not be scanned by a red laser, nor will a frozen package that is frosted over. Metallized packages present a particular problem, often requiring the printing of a white background behind the code. Nearly all codes have common features, including left and right codes that prevent “backward” reading of codes by scanners, a “check digit” that compares with the sum of the digits in the code, such that if the last digit in the sum and the check digit do not match, the scan is rejected.

RFID Coding

Radio Frequency Identification Device (RFID) coding, an outgrowth of powered (*active*) radar aircraft recognition systems in the World War II, uses embedded radio-respondent chips to transmit data when queried by external reader. First versions of modern, microchip methods powered solely by the reader’s interrogatory radio signal (*passive* tags) were used by zoologist Michael Beigel to identify otherwise indistinguishable penguins in the Antarctic. RFID coding is used as a low-labor means of tracking inventory that cannot be accessed for bar-code scanning or manual recording, verifying security of items, and providing an alternate means of retail checkout. It enables *Electronic Point of Sale* (EPOS) operations, first implemented in South Africa in the 1990s.

These have been adapted to other high-value assets of all types using both passive and active tags. Frequencies range from under 135 kHz to over 2MHz, and tags are available in nearly any size needed, from roughly 1 mm² to large self-powered units on shipping containers and construction equipment. Implementation is severely limited by interrogation signal’s ability to penetrate layers of stacked product because interrogation transceiver power is limited to 500 mW in Europe and 4,000 mW (4W) in the United States. Currently, consumer-level RFID tags only carry UPC-level information plus a serial number (typically 64 bits). Demands by large retailers in the mid-2000s drove a rush to implement RFID-tagging systems for products, but the effort stalled at the pallet-tag level because of problems with penetrating large quantities of goods and the persistently high cost of tags. It is inevitable that this system or something offering similar features will be implemented so that not only checkout and inventorying operations can be rendered nearly automatic, but that *smart shelves* can track goods movement within stores. This final – and in some sense invisible – type of “printing” (or information conveyance) is likely to have enormous implications as marketing, distribution, and retail systems become faster, smarter, and more diverse.

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