7 Plastics in Food Packaging

Mark J. Kirwan, Sarah Plant and John W. Strawbridge

7.1 INTRODUCTION

7.1.1 Definition and background

The most recent EU Directive relating to 'plastic materials and articles intended to come into contact with foodstuffs' (reference 2004/19/EC) defines *plastics* as being: 'organic macromolecular compounds obtained by polymerisation, polycondensation, polyaddition or any similar process from molecules with a lower molecular weight or by chemical alteration of natural macromolecular compounds.'

Plastics are widely used for packaging materials and in the construction of food processing plant and equipment, because:

- they are flowable and mouldable (under certain conditions), to make sheets, shapes and structures
- they are generally chemically inert, though not necessarily impermeable
- they are cost effective in meeting market needs
- they are lightweight
- they provide choices in respect of transparency, colour, heat sealing, heat resistance and barrier properties

Referring again to the directive, *molecules with a lower molecular weight* are defined as monomers that can combine with others to form *macromolecular compounds* known as polymers (a word derived from Greek, meaning *many part*s).

The first plastics were derived from natural raw materials and, subsequently, in the first half of the twentieth century, from coal, oil and natural gas. Polyethylene, the most widely used plastic today, was invented in 1933 and was used in packaging from the late 1940s onwards in the form of squeeze bottles, crates for fish (replacing wooden boxes) and film and extrusion coatings on paper-board for milk cartons.

In Europe, nearly 40% of all plastics is used in the packaging sector, and packaging is the largest sector of plastics usage (PlasticsEurope). About 50% of Europe's food is packed in plastic packaging (British Plastics Federation (BPF)).

Plastics have properties of strength and toughness. For example, polyethylene terephthalate (PET) film has a mechanical strength similar to that of iron, but under load the PET film will stretch considerably more than iron before breaking.

Food and Beverage Packaging Technology, Second Edition. Edited by Richard Coles and Mark Kirwan.

Specific plastics can meet the needs of a wide temperature range, from deep frozen food processing (−40°C) and storage (−20°C) to the high temperatures of retort sterilisation (121°C), and reheating of packaged food products by microwave (100°C) and radiant heat (200°C). Most packaging plastics are thermoplastic, which means that they can be repeatedly softened and melted when heated. This feature has several important implications for the use and performance of plastics, as in the forming of containers, film manufacture and heat sealability.

Thermosetting plastics are materials that can be moulded only once by heat and pressure. They cannot be re-softened, as reheating will cause the material to degrade. Thermosetting plastics, such as phenol formaldehyde and urea formaldehyde, are used for threaded closures in cosmetics, toiletries and pharmaceutical packaging but are not used to any great extent for food packaging.

Plastics are used in the packaging of food because they offer a wide range of appearance and performance properties that are derived from the inherent features of the individual plastic material and how it is processed and used.

Plastics are resistant to many types of compound – they are not very reactive with inorganic chemicals, including acids, alkalis and organic solvents – thus, making them suitable, i.e. inert, for food packaging. Plastics do not support the growth of micro-organisms.

Some plastics may absorb some food constituents, such as oils and fats, and hence, it is important that thorough testing is conducted to check all food applications for absorption and migration.

Gases, such as oxygen, carbon dioxide and nitrogen together with water vapour and organic solvents, permeate through plastics. The rate of permeation depends on the following:

- type of plastic
- thickness and surface area
- method of processing
- concentration or partial pressure of the permeant molecule
- Storage temperature

Plastics are chosen for specific technical applications taking the specific needs, in packing, distribution and storage, and use of the product into consideration, as well as for marketing reasons, which can include considerations of environmental perception.

7.1.2 Use of plastics in food packaging

Plastics are used as containers, container components and flexible packaging. In usage, by weight, they are the second most widely used type of packaging and first in terms of value with over 50% of all goods being packaged in plastic. Examples are as follows:

- rigid plastic containers, such as bottles, jars, pots, tubs and trays
- flexible plastic films in the form of bags, sachets, pouches and heat-sealable flexible lidding materials
- plastics combined with paperboard in liquid packaging cartons
- expanded or foamed plastic for uses where some form of insulation, rigidity and the ability to withstand compression is required
- plastic lids and caps and the wadding used in such closures
- diaphragms on plastic and glass jars to provide product protection and tamper evidence

- plastic bands to provide external tamper evidence
- pouring and dispensing devices
- to collate and group individual packs in multipacks, e.g. Hi-cone rings for cans of beer, trays for jars of sugar preserves, etc
- plastic films used in cling, stretch and shrink wrapping
- films used as labels for bottles and jars, as flat glued labels or heat shrinkable sleeves
- components of coatings, adhesives and inks

Plastic films may be combined with other plastics by co-extrusion, blending, lamination and coating to achieve properties that the components could not provide alone. Co-extrusion is a process that combines layers of two or more plastics together at the point of extrusion. Lamination is a process where two or more layers of plastics are combined together with the use of adhesives. Different plastic granules can be blended together prior to extrusion. Several types of coating processes are available to apply plastic coatings by extrusion, deposition from either solvent or aqueous mixtures or by vacuum deposition.

Plastics are also used as coatings and in laminations with other materials, such as regenerated cellulose film (RCF), aluminium foil, paper and paperboard to extend the range of properties that can be achieved. Plastics may be incorporated in adhesives to increase seal strength, initial tack and low temperature flexibility.

Plastics can be coloured, printed, decorated or labelled in several ways, depending on the type of packaging concerned. Alternatively, some plastics are glass clear, others have various levels of transparency, and their surfaces can be glossy or matte.

Plastics are also used to store and distribute food in bulk, in the form of drums, intermediate bulk containers (IBCs), crates, tote bins, fresh produce trays and plastic sacks, and are used for returnable pallets, as an alternative to wood.

The main reasons why plastics are used in food packaging are that they protect food from spoilage, can be integrated with food processing technology, do not interact with food, are relatively light in weight, are not prone to breakage, do not result in splintering and are available in a wide range of packaging structures – shapes and designs that present food products cost effectively, conveniently and attractively.

7.1.3 Types of plastics used in food packaging

The following are the types of plastics used in food-packaging:

- polyethylene (PE)
- polypropylene (PP)
- polyesters (PET, PEN, PC) (*Note*: PET is referred to as PETE in some markets)
- ionomers
- ethylene vinyl acetate (EVA)
- polyamides (PA)
- polyvinyl chloride (PVC)
- polyvinylidene chloride (PVdC)
- polystyrene (PS)
- styrene butadiene (SB)
- acrylonitrile butadiene styrene (ABS)
- ethylene vinyl alcohol (EVOH)

- polymethyl pentene (TPX)
- high nitrile polymers (HNP)
- fluoropolymers (PCTFE/PTFE)
- cellulose-based materials
- polyvinyl acetate (PVA)

Many plastics are better known by their trade names and abbreviations. In the European packaging market, PE constitutes the highest proportion of consumption, with over 50% of the market by weight, and four others, PP, PET, PS (including expanded polystyrene or EPS) and PVC, comprise the bulk of the remaining market (*source*: BPF). The percentages may vary in other markets, but the ranking is similar. The other plastics listed meet particular niche needs, such as improved barrier, heat sealability, adhesion, strength or heat resistance.

These materials are all thermoplastic polymers. Each is based on one, or more, simple compound(s) or monomer(s). An example of a simple monomer would be ethylene, which is derived from oil and natural gas. It is based on a specific arrangement of carbon and hydrogen atoms. The smallest independent unit of ethylene is known as a molecule, and it is represented by the chemical formula, C_2H_4.

Polymerisation results in joining thousands of molecules together to make polyethylene. When the molecules join end to end, they form a long chain. It is possible for molecules to proliferate as a straight chain or as a linear chain with side branches. The length of the chain, the way the chains pack together and the degree of branching affect properties, such as density, crystallinity, gas and water vapour barrier, heat sealing, strength, flexibility and processability.

The factors that control polymerisation are temperature, pressure, reaction time, concentration, chemical nature of the monomer(s), and of major significance, the catalyst(s). A catalyst controls the rate and type of reaction but is not, itself, changed permanently. The introduction of metallocene (cyclopentadiene) catalysts has resulted in the production of high-performance plastics and has had a major impact on the properties of PE, PP and other plastics, such as PS. In some cases, the resulting polymers are virtually new polymers with new applications, e.g. breathable PE film for fresh produce packing, and sealant layers in laminates and co-extrusions.

It is appropriate to consider PE as a family of related PEs that vary in structure, density, crystallinity and other properties of packaging importance. It is possible to include other simple molecules in the structure, and all these variables can be controlled by the conditions of polymerisation – heat, pressure, reaction time and the type of catalyst.

All PEs have certain characteristics in common, which polymerisation can modify, some to a greater and some to a lesser extent, but all PE's will be different from, for example all polypropylenes (PP) or the family of polyesters (PET).

Similar considerations apply to all the plastics listed; they are all families of related materials, with each family originating from one or more type(s) of monomer molecule. It is also important to appreciate the fact that plastics are continually being developed, i.e. modified in the polymerisation process, to enhance specific properties to meet the needs of the:

- manufacture of the film, sheet, moulded rigid plastic container, etc
- end use of the plastic film, container, etc

In the case of food packaging, end use properties relate to performance properties, such as strength, permeability to gases and water vapour, heat sealability and heat resistance, and optical properties, such as clarity.

Additionally, the way the plastic is subsequently processed and converted in the manufacture of the packaging film, sheet, container, etc. will also have an effect on the properties of that packaging item.

7.2 MANUFACTURE OF PLASTICS PACKAGING

7.2.1 Introduction to the manufacture of plastics packaging

Plastic raw material, also known as resin, is usually supplied by the polymer manufacturer in the form of pellets although plastics in powder form are used in some processes. Whilst some plastics are used to make coatings, adhesives or additives in other packaging-related processes, the first major step in the conversion of plastic resin into films, sheets, containers, etc. is to change the pellets from solid to liquid (or molten) phase in an extruder.

The plastic is melted by a combination of high pressure, friction and externally applied heat. This is done by forcing the pellets along the barrel of an extruder using a specially designed, polymer-specific, screw under controlled conditions that ensures the production of a homogeneous melt prior to extrusion (Fig. 7.1).

In the manufacture of film and sheet, the molten plastic is then forced through a narrow slot or die. In the manufacture of rigid packaging, such as bottles and closures, the molten plastic is forced into shape using a precisely machined mould.

7.2.2 Plastic film and sheet for packaging

Generally, films are by definition less than 100 μm thick (1 micron is 0.000001 m or 1×10^{-6} m). Film is used to wrap products, to overwrap packaging (single packs, groups of packs, palletised loads), to make sachets, bags and pouches, and is combined with other plastics and other materials in laminates, which in turn are converted into packaging. Plastic sheets in thicknesses up to 200 μm are used to produce semi-rigid packaging, such as pots, tubs and trays.

The properties of plastic films and sheets are dependent on the plastic(s) used and the method of film manufacture together with any coating or lamination. In film and sheet manufacture, there are two distinct methods of processing the molten plastic that is extruded from the extruder die. In the *cast* film process, the molten plastic is extruded through a straight slot die onto a cooled cylinder, known as the chill roll (Fig. 7.2).

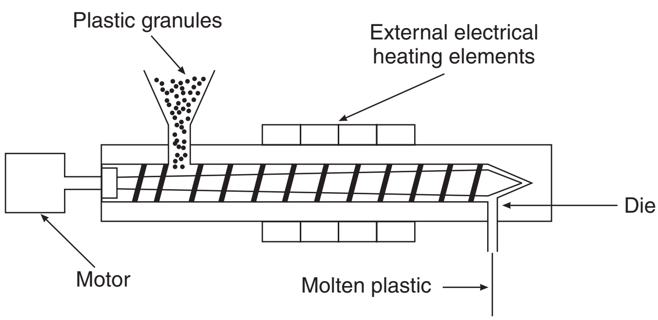

Fig. 7.1 Extruder.

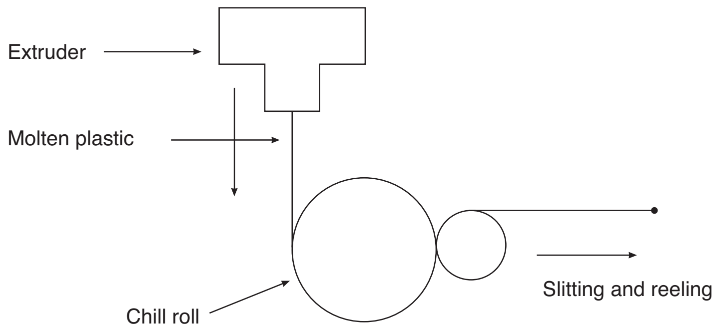

Fig. 7.2 Production of cast film.

In the *blown*, or tubular, film process, the molten plastic is continuously extruded through a die in the form of a circular annulus, so that it emerges as a tube. The tube is prevented from collapsing by maintaining air pressure inside the tube or bubble (Fig. 7.3).

In both these processes, the molten polymer is quickly chilled and solidified to produce a film that is reeled and slit to size.

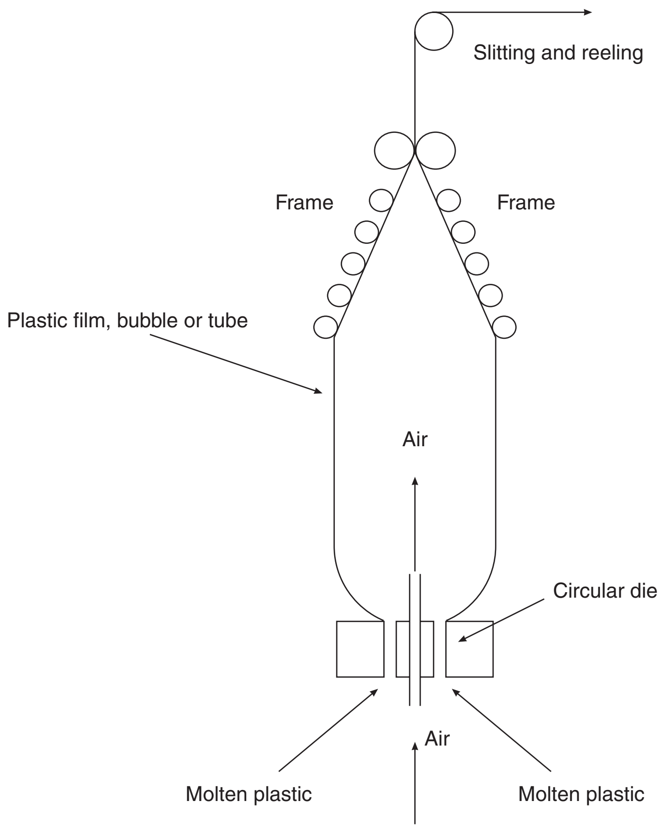

Fig. 7.3 Blown film manufacture.

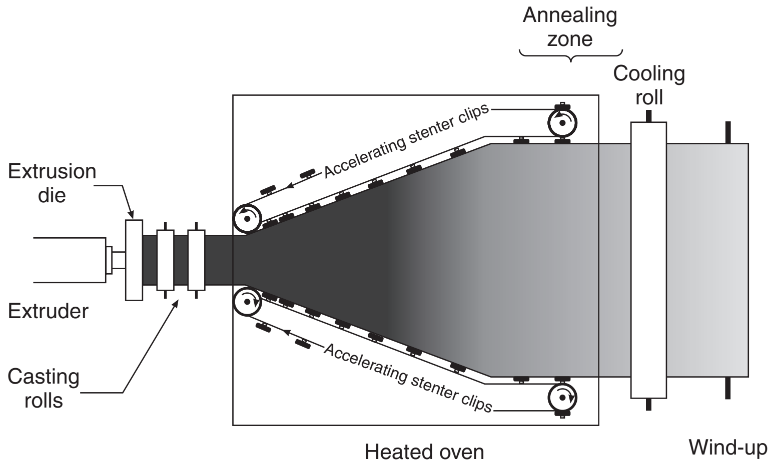

Fig. 7.4 TD orientation by Steiner and MD orientation by acceleration in machine direction. (Courtesy of The Packaging Society.)

For increased strength and improved barrier properties, film can be stretched to realign, or orient, the molecules in both the machine direction (MD), and across the web in the transverse (TD) or cross direction.

In the Stenter-orienting process, transverse stretching of the cast flat sheet is carried out, using clips that grip and pull the film edges, so that the width increases. Stretching in the MD can be achieved with several sets of nip rolls running at faster speeds.

With the blown, or tubular, film process, orienting is achieved by increasing the pressure inside the tube to create a tube with a much larger diameter (Fig. 7.4).

Film stretched in one direction only is described as being *mono-oriented*. When a film is stretched in both the directions, it is said to be *bi-axially orientated*. Packing the molecules closer together improves the gas and water vapour barrier properties. Orientation of the molecules increases the mechanical strength of the film.

Cast films and sheets that are not oriented are used in a range of thicknesses and can be thermoformed by heat and either pressure or vacuum to make the bottom webs of pouches and for single portion pots, tubs, trays or blister packs.

Cast films are also used in flexible packaging because they are considered to be tough; if one tries to tear them, they will stretch and absorb the energy, even though the ultimate tensile strength may be lower than that with an oriented equivalent.

Oriented films are brought close to their melting point to anneal or release stresses in them and to minimise the amount of shrinkage that may take place when being heated in a post-production process, such as printing or heat sealing. Failure to anneal heat set films will ensure that they have very unstable thermal characteristics and allow the films to shrink tightly onto cartons or bottles when heated.

It is difficult to puncture or initiate a tear in an oriented film, but once punctured, the alignment of the molecules allows easy proliferation of the rupture and tear. This feature is made use of to assist the opening of film sachets by incorporating a tear-initiating notch mechanically into the sealing area.

Oriented films may have as little as 60% elongation before breaking, where as cast polypropylene, for example, may extend by 600% before finally breaking. This property is exploited to great effect with linear low-density polyethylene (LLDPE), in the application of stretch wrapping, because the non-branching polymer chains allow easy movement of the polymer molecules past each other. By adding special long-chain molecules in the manufacturing process, it is possible to ensure that the film clings to itself.

The majority of plastic films are transparent and not easily coloured by dyeing or adding pigments. In order to develop opacity, films can be cavitated during film manufacture. Cavitation causes internal light scattering, which gives a white or pearlescent appearance. A simple analogy for the light scattering effect is to consider the example of beating and blending egg white with sugar to produce a meringue, which has a white appearance due to the bubbles, trapped inside the beaten egg white. With some plastics, such as cast PE, a chemical compound can be added to the plastic resin, which gives off a gas, such as nitrogen or carbon dioxide, when heated in the film manufacturing process. The small gas bubbles in the plastic cause light scattering, which gives the film a pearlescent appearance.

However, because oriented films are thin, there is the possibility of the bubbles being so large that the film may be ruptured. So instead of using gas bubbles, a shearing compound or powder is added to the polymer, causing internal rupturing of the plastic sheet as it is being stressed. This causes voids in the film and light is scattered across the whole spectrum. Incident white light is reflected inside the film as a result of the differing refractive index between the plastic and free air. The process lowers the density of the film and may give more cost-effective packaging as a result of the increased area yield.

The technique of pigmenting plastics has been developed using compounds, such as calcium carbonate or, more usually, titanium dioxide, to give a white appearance. The addition of such an inorganic filler, however, increases the density by up to 50%, lowering the yield and increasing the risk of mechanically weakening the film. Early attempts to pigment film produced an abrasive surface, and the practice today is to ensure that there is a skin of pure resin on the outer layers that acts as an encapsulating skin to give the film a smooth and glossy surface. White pigmented cast sheet material is used in thermoforming pots and dishes for dairy-based products.

Metallising with a very thin layer of aluminium is an alternative way to achieve opacity by causing a high proportion of incident light to be reflected off the surface away from the film. This technique has the added benefit of improving barrier properties.

Transparency, the opposite of opacity, depends on the polymer concerned and on the way the film has been produced. If the film is allowed to cool down slowly, then large crystals may be formed, and this gives the film a hazy appearance due to the diffraction and scattering of incident light by the crystals. Transparency improves as polymer crystallinity decreases and is also affected by additives in the film. If the size of the additive particle is too large or if, as with slip agents, they migrate to the surface, the film becomes hazy.

The surface of a film needs to be as smooth as possible to enhance the surface for printing. A rough surface will give a matte appearance to the final printed effect, which is usually considered to be less attractive than a shiny, mirror smooth appearance. Furthermore, a rough surface may give packaging machine runability problems, as it may be difficult to make the film slide over machine parts without creating static electricity in the film. This is overcome by incorporating food grade additives in the film. Films will also tend to block and become adhered layer to layer in the reel. Waxes, such as carnauba wax, are added to minimise the blocking. The action of a slip additive, such as silica, depends on the particles of silica migrating to the surface of the film where they act like ball bearings, holding the surfaces apart.

For marketing purposes, it may be desirable to create a unique impact on the shelf at the point of sale, and hence films have been developed that are matte on one side and have a gloss surface on the other. This is done by casting the film against the matte surface of a sand-blasted chill roll.

It is possible to combine streams of molten plastic from separate extruders in the die to make co-extrusions. Higher productivity is achieved for a given thickness of film if the same plastic is extruded in two or more layers and combined in the die to form a single film. Co-extrusion is an area of rapid development, with extruders capable of combining up to seven layers of differing plastics to achieve specific properties and characteristics.

7.2.3 Pack types based on use of plastic films, laminates, etc.

Single films, co-extruded films and coated and laminated films in reel form are used to make plastic bags, sachets, pouches and overwraps.

Plastic bags are made by folding, cutting and sealing with welded seams that are also cut in the same operation. Pouches are usually made from laminates. They may be formed on the packing machine either from one reel by folding, or from two reels and sealing, inside face to inside face on three sides prior to filling and closing. The pouches travel horizontally on these machines with the product filled vertically (Fig. 7.5).

Pouches can have a base gusset or a similar feature, which enables them to stand when filled and sealed. Pouches can be made separately, and they can be filled manually or fed from magazines on automatic filling machines. (Small four-side sealed packs are also referred to as sachets, though the industry is not consistent in naming – the small four side heat sealed packs for tea are referred to as *tea bags).*

Free-flowing products, such as granules and powders can also be filled vertically on form, fill, seal machines where the film is fed vertically from the reel (Fig. 7.6). These packs are formed around a tube, through which the previously apportioned product passes. A longitudinal heat

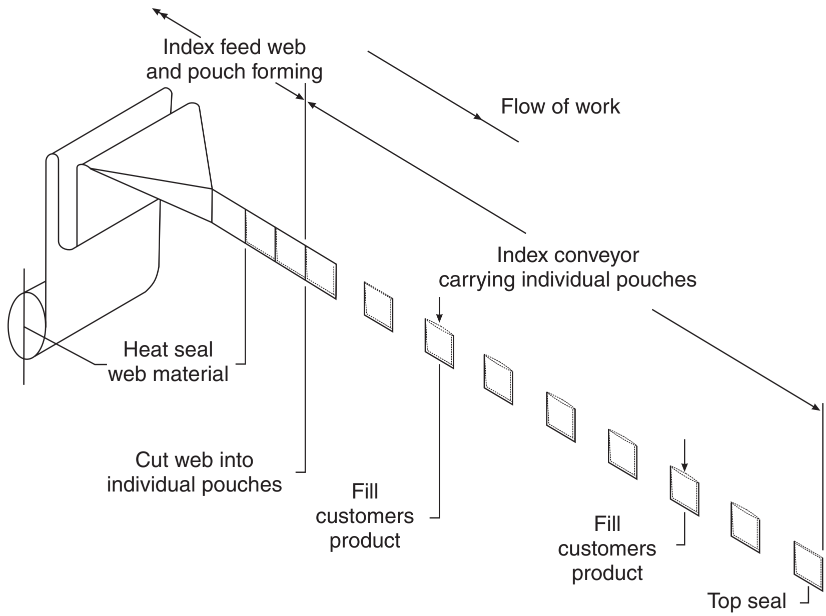

Fig. 7.5 Horizontal form/fill/seal sachet/pouch machine.

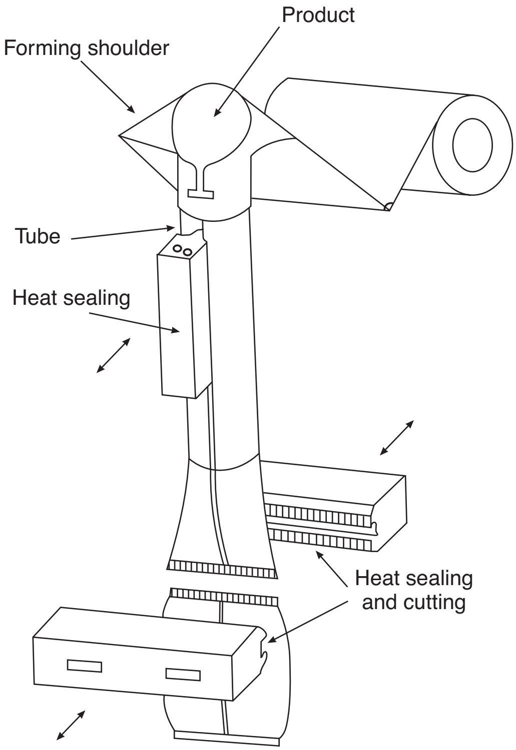

Fig. 7.6 Vertical form/fill/seal (f/f/s) machine.

seal is made either as a fin seal, with inside surface sealing to inside surface, or as an overlap seal, depending on the sealing compatibility of the surfaces. The cross seal is combined with cutting to separate the individual packs.

Solid products, such as chocolate bars, are packed horizontally on form, fill, seal machines (Fig. 7.7). Biscuits can be packed in this way, provided they are collated in a base (plastic) tray, though they are also packed at high speed on roll-wrapping machines with the ends of the film gathered together and heat sealed.

Products packed in cartons are often overwrapped with plastic film, e.g. chocolate assortments and tea bags. The cartons are pushed into the web of film, a longitudinal seal is made and the end seals are neatly folded, envelope style, prior to sealing with a hot platen that presses against the folded ends.

Shrink wrapping is similar to the overwrapping described above, except that the packs pass through the heated tunnel once the cross seal is made – there are no end seals. The film shrinks over the ends of the pack, the extent depending on the width of the film used.

Another packaging format results in either flexible or semi-rigid packaging, depending on the films used, where the film is fed horizontally and cavities are formed by thermoforming. The plastic sheet, such as PET/PE or PA/PE, is softened by heat and made to conform with the dimensions of a mould by pressure and/or vacuum. Where more precise dimensions for wall thickness or shape are required, a plug matching the mould may also be used to help the plastic conform with the mould. The plastic sheet may be cast, cast co-extruded or laminated film, depending on the heat sealing and barrier needs of the application. Products packed in this way

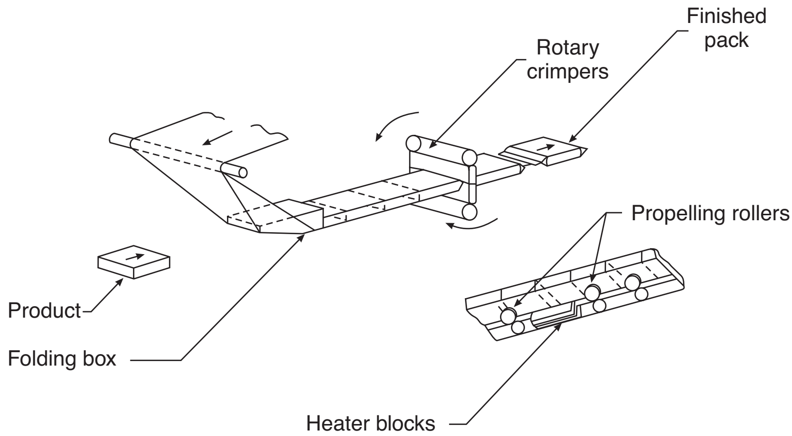

Fig. 7.7 Horizontal form/fill/seal (f/f/s), flowpack type machine.

are typically cheese or slices of bacon. This form of packaging may be sealed with a lidding film laminate under vacuum or in a modified atmosphere (MAP). The various methods of heat sealing are discussed in Section 7.9.2.

7.2.4 Rigid plastic packaging

Bottles are made by extrusion blow moulding. A thick tube of plastic is extruded into a bottle mould that closes around the tube, resulting in the characteristic jointed seal at the base of the container (Fig. 7.8). Air pressure is then used to force the plastic into the shape of the mould. After cooling, the mould is opened and the item removed. (The bottle will show a thin line in the position where the two parts of the mould are joined.) Blow moulding is used for milk bottles (HDPE) and wide mouth jars.

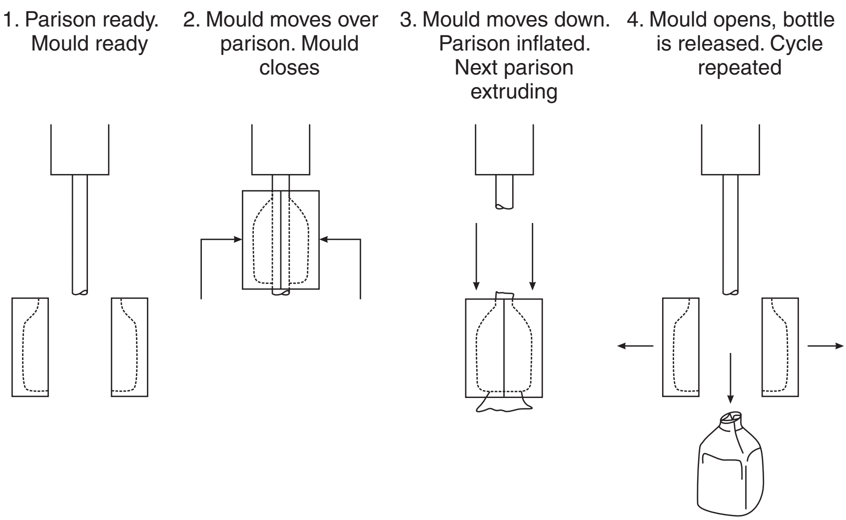

Fig. 7.8 Extrusion blow moulding. (Courtesy of The Packaging Society.)

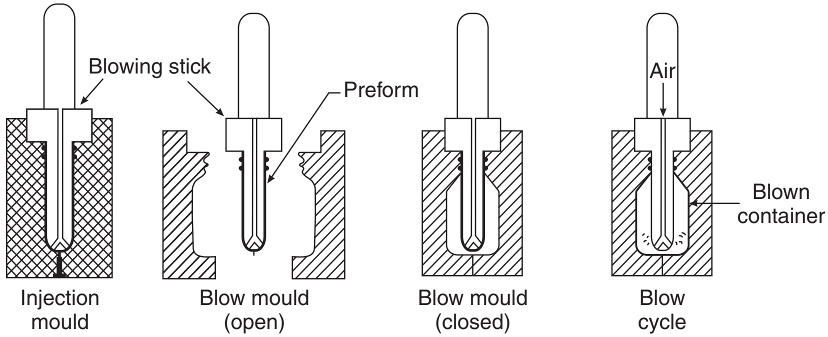

Fig. 7.9 Injection blow moulding. (Courtesy of The Packaging Society.)

It is possible to apply co-extrusion to extrusion blow moulding so that multilayered plastic containers can be made with a sandwich of various plastics. An example would be where high oxygen barrier, but moisture sensitive, EVOH is sandwiched between layers of PP to protect the oxygen barrier from moisture.

This construction will provide for a 12–18 month shelf life for oxygen-sensitive products such as tomato ketchup, mayonnaise and sauces.

If more precision is required in the neck finish of the container, injection blow moulding, a two-stage process, is used. Firstly, a preform or parison, which is a narrow diameter plastic tube, is made by injection moulding (Fig. 7.9). An injection mould is a two-piece mould where the cavity, and the resulting moulded item, is restricted to the actual, precise, dimensions of the preform. This is then blow moulded in a second operation, whilst retaining the accurate dimensions of the neck finish. This process also provides a good control of wall thickness.

A variation of injection and extrusion blow moulding is to stretch the pre-form after softening it at the second stage and then stretching it in the direction of the long axis using a rod (Fig. 7.10). The stretched preform is then blow moulded, which results in biaxial orientation of the polymer molecules, thereby increasing strength, clarity, gloss and gas barrier. Injection stretch blow moulding is used to make PET bottles for carbonated beverages.

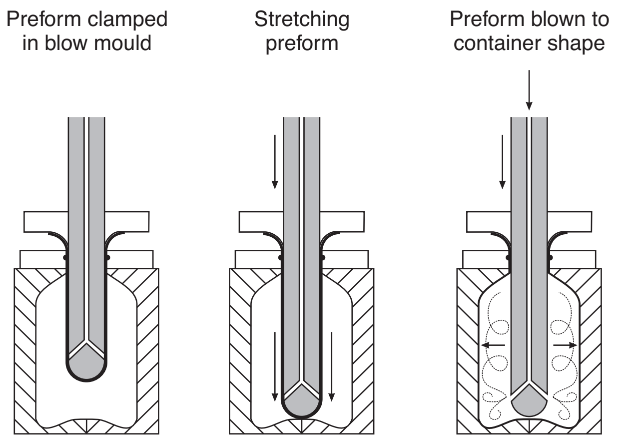

Fig. 7.10 Stretch blow moulding – applicable to both extrusion and injection blow moulding. (Courtesy of The Packaging Society.)

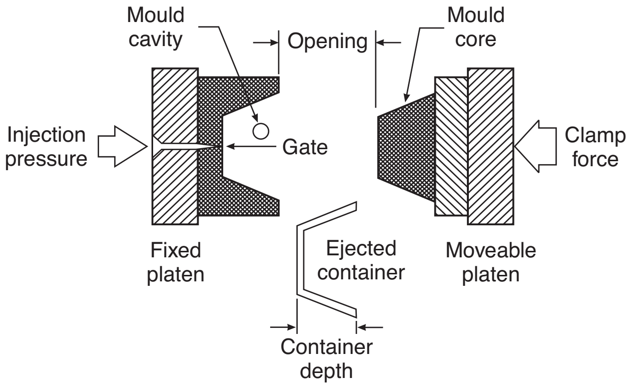

Fig. 7.11 Injection moulding. (Courtesy of The Packaging Society.)

Screw cap and pressure fit closures with accurate profiles are made by injection moulding (Fig. 7.11). Wide mouth tubs and boxes are also made by injection moulding.

Not only are injection-moulded items very accurate dimensionally but they can also be made with a very precise thickness, whether it be thick or thin. It should be noted that co-extrusion is not possible with injection moulding.

Injection-moulded items are recognised by a pinhead-sized protrusion, known as the gate, on the surface, indicating the point of entry of molten plastic into the mould. With injection blow moulding, the gate mark on the pre-form is expanded in the blowing action to a larger diameter circular shape.

There are many food applications for rigid and semi-rigid thermoformed containers. Examples include a wide range of dairy products, yoghurts, etc. in single portion pots, fresh sandwich packs, compartmented trays to segregate assortments of chocolate confectionery and trays for biscuits. Thermoforming can be combined with packing on in-line thermoform, fill and seal machines. These machines can incorporate aseptic filling and sealing (Fig. 7.12).

Profile extrusion is used to make plastic tubing of constant diameter by inserting a suitably pointed rod in the outlet from the die of the extruder. The tubing can be cut to length and an injection moulded end with closure applied. The tube can be filled through the open end, which is then closed by heat sealing. This type of pack is used for food products, such as salad

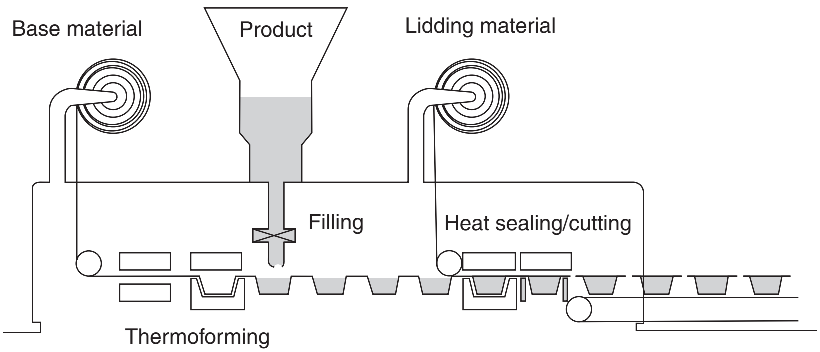

Fig. 7.12 Thermoforming, filling and sealing.

dressings and powders/granules (herbs, spices and seasonings). Where higher barrier properties are required multilayer plastics tubing can be made by co-extrusion. An alternative would be to use an end plug and closure, for example, for loosely packed confectionery products (*Note*: laminated tubes are made with a characteristic heat seal parallel with the long axis).

Foamed plastics are formed by dispersing a gas in the molten polymer, e.g. EPS. Food trays are made from extruded foam sheet by thermoforming. Insulated boxes for the distribution of fresh fish are made by injection moulding.

Plastic bulk containers are used in the food industry for the distribution of ingredients. They can be made by rotational moulding. This process uses plastics, such as low and high density PE, in powder form. A mould is charged with the right amount of polymer, and it is heated and rotated in three axes. This action deposits the plastic on the inside walls of the mould, where it fuses and forms the side walls of the container.

7.3 TYPES OF PLASTIC USED IN PACKAGING

7.3.1 Polyethylene (PE)

PE is structurally the simplest plastic and is made by addition polymerisation of ethylene gas in a high temperature and pressure reactor. A range of low, medium and high density resins are produced, depending on the conditions (temperature, pressure and catalyst) of polymerisation. The processing conditions control the degree of branching in the polymer chain and, therefore, the density and other properties of films and other types of packaging. Polyethylenes are readily heat sealable. They can be made into strong, tough films, with a good barrier to moisture and water vapour. They are not a particularly high barrier to oils and fats or gases, such as carbon dioxide and oxygen compared with other plastics, although barrier properties increase with density. The heat resistance is lower than that of other plastics used in packaging, with a melting point of around 120°C, which increases as the density increases.

Polyethylene is not a conductor of electricity and was first used as an insulator in the 1940s. PE films are therefore highly susceptible of generating a static charge and need to have antistatic, slip agents and anti-blocking compounds added to the resin to assist film manufacturing, conversion and use. Polyethylene is the most widely used in tonnage terms and is cost effective for many applications. It is the workhorse of the flexible films industry. Polymer plants can be found in all countries around the world, supplying specialist film-making polymers.

LDPE or low density PE is easily extruded as a tube and blown to stretch it by a factor of three times the original area. It is commonly manufactured around 30 μm, with newer polymers allowing down gauging to 20 or 25 μm within a density range 0.910–0.925 g/cm^3.

It is possible to colour the films by blending pigment with the polymer prior to extrusion. Where extruders have more than one die, it is possible to form films with two or more layers of the same material or to produce co-extruded films comprised of layers of different plastic materials. With three extruders, it is possible to produce a film where, for example, a moisture-sensitive polymer, EVOH, is sandwiched between protective layers of PE. EVOH provides a gas and odour barrier, and the PE offers good heat-sealing properties and a substrate for printing.

PE film melts at relatively low temperatures and welds to itself when cut with a hot wire, or blade, to form effective seals. For packaging, it is possible to use either premade bags or form/fill/seal machines using flat film in reel form. A major use of white pigmented LDPE film is for making bags for holding frozen vegetables.

By laminating to other substrates with adhesives, or extruding the PE polymer onto another material, or web, it is possible to make strong sachets, pouches and bags with good seal integrity, as the PE flows to fill holes in the sealing area or around contaminants in the seal.

PE and other plastics are also used in combination with paperboard to make the base material for liquid packaging cartons. Major uses of PE film are in shrink and stretch wrapping for collating groups of packs and for securing pallet size loads.

LLDPE (linear low-density PE) film has a density range similar to that of LDPE. It has short side chain branching and is superior to LDPE in most properties, such as tensile and impact strength and also in puncture resistance. A major use has been the pillow pack for liquid milk and other liquid foods.

LDPE and LLDPE can be used in blends with EVA to improve strength and heat sealing. There is a degree of overlap in application between LDPE and LLDPE, due to the fact that there are differences in both, as a result of the conditions of polymer manufacture and on-going product development. The thickness used for specific applications can vary, and this can also have commercial implications.

MDPE or medium-density PE film is mechanically stronger than LDPE and, therefore, used in more demanding situations. LDPE is co-extruded with MDPE to combine the good sealability of LDPE with the toughness and puncture resistance of MDPE, e.g. for the inner extrusion coating of sachets for dehydrated soup mixes.

HDPE or high-density PE is the toughest grade and is extruded in the thinnest gauges. This film is used for boil-in-the-bag applications. To improve heat sealability, HDPE can be co-extruded with LDPE to achieve peelable seals where the polymer layers can be made to separate easily at the interface of the co-extrusion.

A grade of HDPE film is available with either TD mono-axial orientation or biaxial orientation. This film is used for twist wrapping sugar confectionery and for lamination to oriented PP (OPP). The TD-oriented grade easily tears across the web but is more difficult to tear along the web. Being co-extruded, a heat-sealable layer is applied to enable the film to run on conventional form/fill/seal machines. The biaxially oriented film has properties similar to that of OPP but has a higher moisture vapour barrier. It may be coated in the same way as OPP, including metallising, to give a high-barrier performance film with the good sealing integrity associated with PE.

HDPE is injection moulded for closures, crates, pallets and drums, and rotationally moulded for intermediate bulk containers (IBCs). A major application of HDPE is for blow-moulded milk containers with a capacity 0.5–3 L.

7.3.2 Polypropylene (PP)

PP is an addition polymer of propylene formed under heat and pressure using Ziegler-Natta type catalysts to produce a linear polymer with protruding methyl (CH_2) groups. The resultant polymer is a harder and denser resin than PE and more transparent in its natural form. The use of PP developed from the 1950s onwards. PP has the lowest density and the highest melting point of all the high volume usage thermoplastics and has a relatively low cost. This versatile plastic can be processed in many ways and has many food packaging applications in both flexible film and rigid form.

The high melting point of PP (160°C) makes it suitable for applications where thermal resistance is needed, for example in hot filling and microwave packaging. PP may be extrusion laminated to PET or other high-temperature resistant films to produce heat-sealable webs that can withstand temperatures of up to 115–130°C, for sterilising and use in retort pouches.

The surfaces of PP films are smooth and have good melting characteristics. PP films are relatively stiff. When cast, the film is glass-clear and heat sealable. It is used for presentation applications to enhance the appearance of the packed product. Unlike PE, the cast film becomes brittle just below 0°C and exhibits stress cracking below −5°C and, hence, has to be used in a laminate if the application requires deep freeze storage. OPP film, on the other hand, is suitable for use in frozen storage.

PP is chemically inert and resistant to most commonly found chemicals, both organic and inorganic. It is a barrier to water vapour and has oil and fat resistance. Aromatic and aliphatic hydrocarbons are, however, able to be dissolved in films and cause swelling and distortion. PP is not subject to environmental stress cracking (ESC). (ESC is a surface phenomenon whereby cracks can appear in moulded plastic as a result of contact with materials that affect the surface structure in critical parts of the design. This can lead to cracking without actually degrading the surface. There are specific tests to check for ESC, and shelf life tests with the actual product to be packed should also be carried out.)

Orientation increases the versatility of PP film. Oriented PP film (OPP or BOPP) was the first plastic film to successfully replace regenerated cellulose film (RCF) in major packaging applications, such as biscuit packing. OPP films do not weld or heat seal together easily, as the melting temperature is close to the shrinkage temperature of the film and the surfaces spring apart when being sealed. However, acrylic-coated OPP has good runnability, including heat sealing, on packing machines, designed for RCF, though improved temperature control of the heat-sealing equipment is required. Acrylic coatings also offer good odour-barrier properties. Low temperature sealing water-based coatings are also available to provide improved runnability on packing machines.

An improved barrier film for both gases and water vapour is produced by coating with PVdC. This film is used as a carton overwrap for assortments of chocolate confectionery and for tea bags, providing excellent flavour and moisture barrier protection in both cases. One-side coated EVOH coatings are also available for use in laminations. PP films can be metallised and heat seal coated to produce a high gas and water vapour barrier film.

Many of the PP films are used in the form of laminations with other PP and PE films. This allows for the reverse-side printing of one surface, which is then buried inside the subsequent laminate.

Orienting, or extending, the film, typically, by a factor of 5, in both the machine and transverse direction, increases the ultimate tensile strength and some barrier properties, such as the barrier to water vapour. Orienting in one direction binds the polymer molecules tightly to each other. However, they behave in a similar way to cotton fibres in a ball of cotton wool, in that they demonstrate low mechanical strength. When cotton fibres are spun, the resulting thread has a high strength. In the same way, orienting the polymer fibres biaxially in two directions results in a film with a high strength. This amount of biaxial orientation increases the area compared with the area extruded by a factor of 25, and the film is, proportionately, reduced in thickness. It is possible to produce oriented film with a consistent thickness of 14 μm for packaging.

PP and PE have the lowest surface tension values of the main packaging plastics and require additional treatment to make them suitable for printing, coating and laminating. This is achieved with a high-voltage electrical (corona) discharge, ozone treatment or by gas jets (Grieg *et al.*, 2000). These treatments lightly oxidise the surface by providing aldehydes and ketones that increase the surface energy and, therefore, improve the adhesion, or keying, of coatings, printing inks and adhesives.

OPP film is produced in widths of up to 10 m or more to achieve cost-effective production. The limiting factors in production are either extrusion capacity for the thicker films or winding speed for the very thin films.

Most extrusion units today have more than one extruder, thereby enabling production to run at higher speeds and the use of different polymers feeding into one common die slot. Typically, a film will be made up of three or five layers of resin. The centre layer may be a thick core, either opaque or transparent, secondary polymer layers may have special barrier properties or pigmentation, and the outer layers may be pure PP resin to give gloss to the surface and/or protect the inner resins should they be moisture sensitive, as is the case with EVOH. In addition, thin layers of special adhesion-promoting resins, known as tie layers, may also be extruded.

The range of food products packed in PP films include biscuits, crisps (chips) and snack foods, chocolate and sugar confectionery, ice cream and frozen food, tea and coffee. Metallised PP film can be used for snacks and crisps (chips) where either a higher barrier or longer shelf life is required. White opaque PP films and films with twist wrapping properties are available. There are several types of heat seal coating, and in addition, it is possible for converters to apply cold seal coatings on the non-printing side, in register with the print, for wrapping heat-sensitive food products, such as those involving chocolate.

Paperboard can be extrusion coated with PP for use as frozen/chilled food trays that can be heated by the consumer in microwave and steam-heated ovens. Major food applications of PP are for injection-moulded pots and tubs for yoghurt, ice cream, butter and margarine. It is also blow-moulded for bottles and wide mouth jars. PP is widely used for the injection moulding of closures for bottles and jars.

PP can provide a durable living hinge that is used for flip top injection moulded lids that remain attached to the container when opened, e.g. sauce dispensing closure and lid.

It is used in thermoforming from PP sheet, as a monolayer, for many food products, such as snacks, biscuits, cheese and sauces. In co-extrusions with PS, EVOH and PE it is used for the packaging of several types of food product including those packed aseptically, by hot filling, and in microwaveable and retortable packs.

7.3.3 Polyethylene Terephthalate (PET or PETE)

Polyesters are condensation polymers formed from ester monomers, resulting from the reaction of a carboxylic acid with an alcohol. There are many different types of polyester, depending on the monomers used. When terephthalic acid reacts with ethylene glycol and polymerises, the result is PET.

PET can be made into film by blowing or casting. It can be blow moulded, injection moulded, foamed, extrusion coated on paperboard and extruded as sheet for thermoforming. PET can be made into a biaxially oriented range of clear polyester films produced on essentially the same type of extrusion and Stenter-orienting equipment as OPP. Film thicknesses range from thinner than 12 μm for most polyester films to around 200 μm for laminated composites. No processing additives are used in the manufacture of PET film.

Polyesters have much higher heat resistance than many plastics and, when oriented, have very high mechanical strength. The ester has more radicals that may link with other chemicals, consequently making the surface more reactive to inks and not as resistant to chemicals as compared with polyolefins, such as PE and PP.

PET melts at a much higher temperature than PP, typically 260°C, and due to the manufacturing conditions does not shrink below 180°C. This means that PET is ideal for high-temperature applications using steam sterilisation, boil in-the-bag and for cooking or reheating in microwave or conventional radiant heat ovens. The film is also flexible in extremes of cold, down to −100°C. Heat sealable versions are available, and it can also be laminated to PE to give good heat-sealing properties. Coated versions, using PVdC, give a good gas barrier and heat-sealing capability.

PET is a medium oxygen barrier on its own but becomes a high barrier to oxygen and water vapour when metallised with aluminium. This is used for vacuumised coffee and bag-in-box liquids, where it is laminated with EVA on both sides to produce highly effective seals. It is also used in snack food flexible packaging for products with a high fat content, requiring barriers to oxygen and ultra violet (UV) light. Metallised PET, either as a strip or as a flexible laminate, is used as a susceptor in microwaveable packaging.

Reverse printed PET film is used as the external ply on f/f/s pouches where it provides a heat-resistant surface for contact with the heat-sealing bars.

The amorphous cast grades can be used as the bottom web in formed applications that are lidded with a heat-sealable grade of PET. These packs can be reheated in microwave and conventional ovens. (*Note*: all polymers are amorphous in the molten state, and rapid cooling fixes the polymer chains in this random state whereas slow cooling allows the molecules to realign themselves in a more formal crystalline state. In the case of PET, the amorphous state is a tough transparent material and the crystalline state is white and brittle.)

PET film is also used as the outer reverse-printed ply in retort pouches, providing strength and puncture resistance, where it is laminated with aluminium foil and either PP or HDPE. PET can be oxide coated with SiO_2 to improve the barrier, whilst remaining transparent, retortable and microwaveable.

Paperboard is extrusion coated with PET for use as ready meal trays that can be reheated in microwave or conventional radiant heat ovens, i.e. dual ovenable. The PET coated side of the paperboard is on the inside of the tray that is erected by corner heat sealing.

PET is the fastest growing plastic for food packaging applications as a result of its use in all sizes of carbonated soft drinks and mineral water bottles that are produced by injection stretch blow moulding. PET bottles are also used for edible oils, as an alternative to PVC.

A foamed coloured PET sheet has been developed under the trade name Escofoam™, which can be laminated and used as the bottom web in thermoformable f/f/s packaging with a printed, peelable seal, top web, e.g. with MAP for fresh meat and fish. A high-barrier laminate, requiring the use of an extruded tie polymer, acting as an adhesion promoter, would comprise PE/EVOH/PE/PET foam.

7.3.4 Polyethylene naphthalene dicarboxylate (PEN)

PEN is a condensation polymer of dimethyl naphthalene dicarboxylate (DNC) and ethylene glycol. This polyester polymer has created interest in the last few years due to its improved gas and water vapour barrier and strength properties compared to PET.

It is UV resistant and has higher temperature resistance compared with PET. It can be made into film and blow moulded for bottles.

PEN is a modified polyester resin from BP Chemicals. It is available as either a monopolymer PEN, a copolymer with PET, or a PET/PEN blend. The selection of a specific naphthalate containing resin is dependent on the performance and cost requirements of the particular application.

Suggested applications include one-trip beer/soft drinks bottles, returnable/refillable beer/mineral water bottles, sterilisable baby feeding bottles, hot fill applications, sports drinks, juices and dehydrated food products in flexible packaging. PEN is more expensive than PET, and this has limited its food packaging applications. Because of its relatively high cost, it is likely that PEN containers will only be suitable for use in closed loop returnable packaging systems.

PEN films can be vacuum metallised or coated with Al/Si oxides. It is claimed that the lamination of a metallised PEN film, Hostaphan RHP coated with SiOx from Mitsubishi Plastics Inc, to PE has been used for powdered baby milk. SiOx coated PEN film may be developed for retorting so that it could be used, for example, for soup in stand-up pouches.

7.3.5 Polycarbonate (PC)

PC is a polyester containing carbonate groups in its structure. It is formed by the polymerisation of the sodium salt of bisphenolic acid with phosgene. It is glass clear, heat resistant and very tough and durable. PC is mainly used as a glass replacement in processing equipment and for glazing applications. Its use in packaging is mainly for large, returnable/refillable 3–6 L water bottles. It is used for sterilisable baby feeding bottles and as a replacement in food service. (This polycarbonate is not to be confused with the thermosetting polycarbonate used in contact lens manufacture.) It has been used for returnable milk bottles, ovenable trays for frozen food and if co-extruded with nylon could be used for carbonated drinks.

7.3.6 Ionomers

Ionomers are polymers formed from metallic salts of acid copolymers and possess interchange ionic crosslinks that provide the characteristic properties of this family of plastics. The best known in food packaging applications is Surlyn® from Dupont, where the metallic ions are zinc or sodium and the copolymer is based on ethylene and methacrylic acid. Surlyn® is related to PE. It is clear, tougher than PE, having high puncture strength, and has excellent oil and fat resistance. It is, therefore, used where products contain essential oils, as in the aseptic liquid packaging of fruit juices in cartons, and fat containing products, such as snack foods in sachets. It has excellent hot tack and heat-sealing properties, leading to increased packing line speeds and output – even sealing when the seal area is contaminated with product. It is used in the packaging of meat, poultry and cheese. It is particularly useful in packing product with sharp protrusions.

Surlyn® grades are available for use in conventional extrusion and co-extrusion blown and cast film, and extrusion coating on equipment designed to process PE. It is also used as a tie or graft layer to promote adhesion between other materials, such as PE onto aluminium foil or PET to nylon. An ionomer/ionomer heat seal can be peelable if PE is used, adjacent to one of the ionomer layers and buried in the laminate, e.g. PET/PE/Ionomer.

In food packaging, ionomer films, including coextruded films, are used in laminations and extrusion coatings in all the main types of flexible packaging. These include:

- vertical and horizontal f/f/s
- vacuum and MAP packing
- four-side sealed pouches and twin-web pouches with one web thermoformed

- inner ply of paperboard composite cans, e.g. aluminium foil/ionomer
- diaphragm or membrane seals
- ionomers are used in laminated and coated form with PET, PA, PP, PE, aluminium foil, paper and paperboard

7.3.7 Ethylene vinyl acetate (EVA)

EVA is a copolymer of ethylene with vinyl acetate. It is similar to PE in many respects, and it is used, blended with PE, in several ways. The properties of the blend depend on the proportion of the vinyl acetate component. Generally, as the VA component increases, sealing temperature decreases and impact strength, low temperature flexibility, stress resistance and clarity increase. At a 4% level, it improves heat sealability, at 8% it increases toughness and elasticity, along with improved heat sealability, and at higher levels, the resultant film has good stretch wrapping properties. EVA with PVdC is a tough high-barrier film that is used in vacuum packing large meat cuts and with metallised PET for bag-in-box liners for wine.

Modified EVAs are available for use as peelable coatings on lidding materials, such as aluminium foil, OPP, OPET and paper. They enable heat sealing, resulting in controllable heat seal strength for easy, clean peeling. These coatings will seal to both flexible and rigid PE, PP, PET, PS and PVC containers. (An alternative approach to achieving a peelable heat seal is to blend non-compatible material with a resin, which is known to give strong heat seal bonds so that the bond is weakened. Modified EVAs are also available for use in this way).

Modified EVAs are also used to create strong interlayer tie bonding between dissimilar materials, e.g. between PET and paper, LDPE and EVOH.

EVA is also a major component of hot melt adhesives, frequently used in packaging machinery to erect and close packs, e.g. folding cartons and corrugated packaging.

7.3.8 Polyamide (PA)

Polyamides (PA) are commonly known as nylon. However, nylon is not a generic name; it is the brand name for a range of nylon products made by Dupont. They were initially used in textiles, but subsequently other important applications were developed including uses in packaging and engineering. Polyamide plastics are formed by a condensation reaction between a diamine and a diacid or a compound containing each functional group (amine). The different types of polyamide plastics are characterised by a number that relates to the number of carbon atoms in the originating monomer. Nylon 6 and related polymer nylon 6,6 have packaging applications. It has mechanical and thermal properties similar to that of PET and, therefore, similar applications.

PA resins can be used to make blown film, and they can be co-extruded. PA can be blended with PE, PET, EVA and EVOH. It can be blow moulded to make bottles and jars that are glass clear, low in weight and have a good resistance to impact.

Biaxially oriented PA film has high heat resistance and excellent resistance to stress cracking and puncture. It has good clarity and is easily thermoformed, giving a relatively deep draw. It provides a good flavour and odour barrier and is resistant to oil and fat. It has a high permeability to moisture vapour and is difficult to heat seal. These features can be overcome by PVdC coating.

They can also be overcome by lamination or co-extrusion with polyethylene, and this structure is used as the bottom thermoformable web, i.e. deep drawn, for packing bacon and cheese in vacuum packs or in gas-flushed packs (MAP or modified atmosphere packaging). The film can be metallised.

PA film is used in retortable packaging in structures, such as PA/aluminium foil/PP. The film is non-whitening in retort processing. PA is relatively expensive compared with, for example, PE, but as it has superior properties, it is effective in low thicknesses.

7.3.9 Polyvinyl chloride (PVC)

If one of the hydrogen atoms in ethylene is replaced with a chlorine atom, the resultant molecule is called vinyl chloride monomer (VCM). Addition polymerisation of vinyl chloride produces PVC.

Unplasticised PVC (uPVC) has useful properties but is a hard, brittle material, and modification is necessary for it to be used successfully. Flexibility can be achieved by the inclusion of plasticisers, reduced surface friction with slip agents, various colours by the addition of pigments and improved thermal processing by the addition of stabilising agents. Care must be exercised in the choice of additives used in film that will be in direct contact with food, particularly with respect to the migration of packaging components into foodstuffs.

Rigid uPVC is used for transparent or coloured compartmented trays for chocolate assortments and biscuits. It is used with MAP for thermoformed trays to pack salads, sandwiches and cooked meats.

Most PVC films are produced by extrusion, using the bubble process. It can be oriented to produce film with a high degree of shrinkability. Up to 50% shrinkage is possible at quite low temperatures. The film releases the lowest energy of the commonly used plastic films when it is heat shrunk around products. It is plasticised, and the high stretch and cling make it suitable for overwrapping fresh produce, e.g. apples and meat in rigid trays using semi-automatic and manual methods.

Printed PVC film is used for heat-shrinkable sleeve labels for plastic and glass containers. It is also used for tamper-evident shrink bands. Thicker grades are thermoformed to make trays that, after filling, are lidded with a heat seal-compatible top web.

PVC has excellent resistance to fat and oil. It can be used in the form of blow moulded bottles for vegetable oil and fruit drinks. It has good clarity. As a film, it is tough, with high elongation, though with relatively low tensile and tear strength. The moisture vapour transmission rate is relatively high, though adequate for the packaging of mineral water, fruit juice and fruit drinks in bottles. PVC softens, depending on its composition, at relatively low temperatures (80–95°C). PVC easily seals to itself with heat, but heat sealing with a hot wire has the disadvantage of producing HCl gas.

The permeability to water vapour and gases depends on the amount of plasticiser used in manufacture. uPVC is a good gas and water vapour barrier, but these properties decrease with increasing plasticiser content. There are grades that are used to wrap fresh meat and fresh produce, where a good barrier to moisture vapour retards weight loss, but the permeability to oxygen allows the product to breathe. This allows fresh meat to retain its red colour and products, such as fruits, vegetables and salads to stay fresh longer by reducing the rate of respiration, especially when packed in a modified atmosphere (MAP).

7.3.10 Polyvinylidene chloride (PVdC)

PVdC is a copolymer of vinyl chloride and vinylidene chloride – the latter forms when two hydrogen atoms in ethylene are replaced by chlorine atoms. PVdC was developed originally by Dow Chemical, who gave it the trade name Saran™.

PVdC is heat sealable and is an excellent barrier to water vapour and gases and to fatty and oily products. As a result of the high gas and odour barrier, it is used to protect flavour and aroma sensitive foods from both loss of flavour and ingress of volatile contaminants. It is used in flexible packaging in several ways:

- *monolayer film*: A well-known application is the Cryovac® range introduced by W.R. Grace and now operated by the Sealed Air Corporation. This includes poultry packing where hot water shrinkable bags are used to achieve a tight wrap around the product. The film can be used in the form of sachets but is less likely to be cost effective compared with other plastic films – some of which may incorporate PVdC as a coating. An interesting use is as sausage and chubb casing
- *co-extrusions*: PVdC is often used in co-extrusion, where, today, extruders incorporate three, five and even seven extrusion layers to meet product protection and packaging machinery needs cost effectively
- *coatings*: These may be applied using solutions in either organic solvents or aqueous dispersions to plastic films, such as BOPP and PET, to RCF and to paper and paperboard

Hence, PVdC is a widely used component in the packaging of cured meats, cheese, snack foods, tea, coffee and confectionery. It is used in hot filling, retorting, low-temperature storage and MAP as well as ambient filling and distribution in a wide range of pack shapes.

7.3.11 Polystyrene (PS)

PS is an addition polymer of styrene, a vinyl compound where a hydrogen atom is replaced with a benzene ring. PS has many packaging uses and can be extruded as a monolayer plastic film, co-extruded as a thermoformable plastic sheet; injection moulded and foamed to give a range of pack types. It is also co-polymerised to extend its properties.

It is less well known as an oriented plastic film, though the film has interesting properties. It has high transparency (clarity). It is stiff, with a characteristic crinkle, suggesting freshness, and has a deadfold property. The clear film is used for carton windows, and white pigmented film is used for labels. The film is printable. It has a low barrier to moisture vapour and common gases, making it suitable for packaging products, such as fresh produce, which need to breathe.

PS is easily processed by foaming to produce a rigid lightweight material that has good impact protection and thermal insulation properties. It is used in two ways: The blown foam can be extruded as a sheet that can be thermoformed to make trays for meat and fish, egg cartons, a variety of fast food packs, such as the clam shell-shaped container, as well as cups and tubs. Thin sheets can be used as a label stock. The foam can also be produced in pellet or bead form that can then be moulded with heat and pressure. This is known as expanded polystyrene or EPS. It can be used as a transit case for fresh fish, with thick walls for insulation.

PS so far described is general purpose polystyrene. The main disadvantage as a rigid or semi-rigid container is the fact that it is brittle. This can be overcome by blending with styrene butadiene co-polymer, SB or SBC, an elastomeric polymer. The blend is known as high-impact polystyrene or HIPS. Blending produces a tougher material. It is translucent and is often used in a white pigmented form. The sheet can be thermoformed for short shelf life dairy products.

HIPS is also used in multilayer sheet extrusion with a variety of other polymers, each of which contributes to the protection and application needs of the product concerned. Other polymers that may be used in this way with HIPS include PE, PP, PET, PVdC and EVOH. The food products packed with these materials include dairy products, such as cream and yoghurt-based desserts, UHT milk, cheese, butter, margarine, jam, fruit compote, fresh meat, pasta, salads, etc. Many of these products are packed aseptically on thermoform, fill and seal machines.

7.3.12 Styrene butadiene (SB)

SB co-polymer is also a packaging polymer in its own right – it is tough and transparent, with a high-gloss surface finish. Blown film has high permeability to water vapour and gases. It is used to pack fresh produce. It is heat sealable to a variety of surfaces. The film has good crease retention, making it suitable for twist wrapping sugar confectionery. Injection-moulded containers with an integral locking closure have a flexible hinge, similar in this respect to PP. It is known as K-resin® in the USA. It can also be used to make thermoformable sheet, injection and blow moulded bottles and other containers with high impact resistance and glass-like clarity. The relatively low density gives SBC a 20–30% yield advantage over other, non-styrenic, clear resins.

7.3.13 Acrylonitrile butadiene styrene (ABS)

ABS is a co-polymer of acrylonitrile, butadiene and styrene, with a wide range of useful properties that can be varied by altering the proportions of the three monomer components. It is a tough material with good impact and tensile strength and good flexing properties. ABS is either translucent or opaque. It is thermoformable and can be moulded. A major use is in large shipping and storage containers (tote boxes), and it has been used for thin-walled margarine tubs and lids.

7.3.14 Ethylene vinyl alcohol (EVOH)

EVOH is a co-polymer of ethylene and vinyl alcohol. It is related to polyvinyl alcohol (PVOH), which is a water-soluble synthetic polymer with excellent film-forming, emulsifying and adhesive properties. It is a high-barrier material with respect to oil, grease, organic solvents and oxygen. It is moisture sensitive and, in film form, is water soluble. PVOH itself has packaging applications in film form but not in food products, and it is used as a coating for BOPP.

EVOH was developed to retain the high-barrier properties of PVOH. It is also an excellent barrier to oxygen and is resistant to the absorption and permeation of many products, especially those containing oil, fat and sensitive aromas and flavours. Though it is moisture sensitive to a much lesser degree than PVOH, it is still necessary to bury it in multilayered co-extruded structures, such as film for flexible packaging, sheets for thermoforming and in blow moulded bottles, so that it is not in contact with liquid.

The other polymers used depend on the application, i.e. the food product and type of pack. PS/EVOH/PS and PS/EVOH/PE sheets are used for processed cheese, pâté, UHT milk and milk-based desserts and drinks. It is also used for MAP of fresh meat and for pasta, salads, coffee and hot filled processed cheese, including portion packed cheese and fruit compote.

A higher-barrier sheet can be constructed with PP/EVOH/PP for pasteurisable and retortable products, such as fruit, pâté, baby food, sauces like ketchup and ready meals, some of which are reheated by microwave. Co-extruded film applications can involve EVOH with nylon, LLDPE and Surlyn® (ionomer) with food products, such as bag-in-box wine, processed and fresh meat.

Extrusion lamination can involve EVOH with PET, LDPE and LLDPE for coffee, condiments and snacks. It is used with PET and PP for tray lidding material. Extrusion lamination of paperboard with EVOH and PE is used for aseptically packed UHT milk and fruit juices where the EVOH layer provides an oxygen barrier as a replacement for aluminium foil. In blow moulding, EVOH is used with PP for sauces, ketchup, mayonnaise and cooking oil and with HDPE for salad dressings and juices. Ketchup and mayonnaise bottles based on EVOH are squeezable.

Small tubes made by profile co-extrusion are used for condiments by incorporating EVOH into structures with LDPE and LLDPE. EVOH is an important polymer in many processing applications providing protection for many types of food product.

7.3.15 Polymethyl pentene (TPX)

TPX is the trade name for methyl pentene co-polymer. It is based on 4-methyl-1-ene and possesses the lowest density of commercially available packaging plastics (0.83 cm^3). It is a clear, heat-resistant plastic that can be used in applications up to 200°C. The crystalline melting point is 240°C (464°F). TPX offers good chemical resistance, excellent transparency and gloss. It can be extruded and injection moulded.

It was introduced by ICI in the 1970s and is now available from Mitsui Chemicals Inc. The main food packaging use is as trays and as an extrusion coating onto paperboard for use in baking applications in the form of cartons and trays for bread, cakes and other cook-in-pack foods. This packaging is dual ovenable, i.e. food packed in this way may be heated in microwave and radiation ovens. The surface of this plastic gives superior product release compared with aluminium and PET surfaces. TPX paperboard coated trays must be formed by the use of interlocking corners as they cannot be erected by heat sealing.

7.3.16 High nitrile polymers (HNP)

HNPs are co-polymers of acrylonitrile. They are used in the manufacture of other plastics, such as ABS and SAN. The nitrile component contributes very good gas and odour barrier properties to the common gases, together with good chemical resistance. HNPs, therefore, offer very good flavour and aroma protection.

A commercially available range of HNPs approved for food packaging is made under the trade name Barex®, introduced by Sohio Chemical and now INEOS Barex. This is a rubber-modified acrylonitrile–methyl acrylate copolymer. Grades are available for blown and cast film, extrusion blow moulding, injection stretch blow moulding and injection moulding. It is a clear, tough, rigid material with a very good gas barrier and chemical resistance. It is used as the inner layer in blow-moulded bottles co-extruded with HDPE. Barex films can be co-extruded as film and sheet or laminated with PE, PP and aluminium foil for flexible packaging applications with food products. Sheet materials can be thermoformed.

7.3.17 Fluoropolymers

Fluoropolymers or fluoroplastics are high-performance polymers related to ethylene where some or all of the hydrogen atoms are replaced by fluorine, and in the packaging polymer a hydrogen is also replaced by a chlorine atom to produce polychlorotrifluoroethylene (PCTFE). The trade names are Aclar® (Honeywell) and Neoflon™ (introduced as Kel-F® by 3 Ms and now manufactured by Daikin America Inc).

This material has the highest water vapour barrier of all the commercially available packaging polymers, is a very good gas barrier and offers high resistance to most chemicals at low temperatures. In many applications, it is a suitable replacement for aluminium foil. It is available as a film or sheet. It is transparent, heat sealable and can be laminated, thermoformed, metallised and sterilised.

It is relatively expensive and is best known as a thermoformable blister pack material laminated with PVC for pharmaceutical tablets. Food packaging applications are possible but are not highlighted at the present time. Polytetrafluoroethylene (PTFE), better known as DuPont Teflon®, is a high melting point, inert and waxy polymer. It is used in the form of tape and coatings on packaging machines to reduce adhesion, where that could be a problem, e.g. heat seal bars, and to reduce friction where packaging materials move over metal surfaces.

7.3.18 Cellulose-based materials

The original packaging film was regenerated cellulose film (RCF). Pure cellulose fibre derived from wood is dissolved and then regenerated by extrusion through a slot, casting onto a drum and following acid treatment, is wound up as film. It is commonly known as Cellophane, though this is in fact a trade name. RCF is not a thermoplastic material in that it is not processed in a molten phase or softened by heat. Cellulose is, however, a high-molecular weight, naturally derived, polymer.

To make it flexible, it is plasticised with humectants (glycol type). The degree of flexibility can be adjusted to suit the application. The degree of flexibility can range from a fairly rigid level to the most flexible, which is known as twist-wrap used to wrap individual units of sugar confectionery. RCF is dead folding so that it keeps a folded, or twist wrapped condition. It is a poor barrier to water vapour, and this property is made use of with products that need to lose moisture, such as pastries and other flour confections, to achieve the correct texture when packed. Plastic films, such as PP or PE, would keep the relative humidity (RH) too high inside such a package and, therefore, encourage mould growth. When dry, RCF is a good barrier to oxygen.

Heat sealability and an improved barrier to water vapour and common gases are achieved by coating. The coatings are either nitrocellulose (MS type) or PVdC (MX type). A range of barrier performances are possible by choice and method of coating. It can be coloured and metallised. (Red coloured breathable RCF secured with a printed label on the base is used to wrap Christmas puddings.) RCF is printable.

RCF can be laminated with paper, aluminium foil, PET, metallised PET and PE to achieve specific levels of performance and appearance. It is resistant to heat and is used in laminates where reheating involves temperatures in the range 220–250°C. Usage today is much reduced with the availability of the lower cost BOPP, which matches RCF in many properties. The pack design is usually a form/fill/seal pouch type. RCF is used in food packaging for gift packs and for packaging that is specified as biodegradable (compostable).

Uncoated thick RCF is used to demonstrate tamper evidence on a bottle. This is done by moistening a small diameter RCF sleeve, slipping it over the bottle closure and top part of the neck and allowing it to dry when it shrinks tightly to the bottle and closure.

Cellulose acetate is also derived from cellulose. It has high transparency and gloss. It can be printed. It has been used as a laminate with paperboard for confectionery cartons and as a window in carton design. In both applications, it is more expensive than BOPP. It has also been replaced by PVC, PET and PP as a sheet material for the manufacture of transparent cartons.

7.3.19 Polyvinyl acetate (PVA)

PVA is a polymer of vinyl acetate that forms a highly amorphous material with good adhesive properties in terms of open time, tack and dry bond strength. The main use of PVA in food packaging is as an adhesive dispersion in water. PVA adhesives are used to seal the side seams of folding cartons and corrugated fibreboard cases and to laminate paper to aluminium foil.

7.4 COATING OF PLASTIC FILMS – TYPES AND PROPERTIES

7.4.1 Introduction to coating

Coatings are applied to the surfaces of plastic films to improve heat-sealing and barrier properties. They are also applied to rigid plastics to improve barrier properties. Traditionally, the most common method of application to film has been by using an etched roll, as this gives consistent and accurate coating with weights up to around 6 g/m^2. This level of coating is commercially available from film manufacturers. If higher coating weights are required, this is normally carried out by converters.

With environmental concerns being an important factor, water-based coating systems have been developed. It is unusual to find solvent-based systems being used today. Where they are used they are mostly alcohol based, with butanol being the highest boiling point solvent used. Priming coats are applied. Where the coating is to be applied to both sides of the film, the primer is applied to both sides simultaneously, using reverse driven gravure rollers. Adhesion to the base film is essential, and hence an adhesive-type coating with antistatic properties is normally used, with a coating weight of less than 1 g/m^2.

Metallised coating using aluminium has been available for some time. This is carried out by converting the aluminium to vapour in a vacuumised chamber and depositing it on the surface of plastic film, paper and paperboard for packaging purposes. More recently, SiOx, a mixture of silicon oxides, has been deposited in thin layers on several plastic films. It is likely that other materials, e.g. DLC, diamond-like coating based on carbon that has been internally applied to PET bottles, will be developed further for both bottles and film.

Extrusion coating is also a method of applying a plastic coating, though this usually refers to the application of plastics to other materials, such as aluminium foil, paper and paperboard. Coating as a technique for improving the properties of plastic film and containers is an active area for innovation.

7.4.2 Acrylic coatings

Acrylic coatings are applied to plastic film, particularly OPP. The coating is glass clear, hard, heat sealable and very glossy. It has an initial sealing temperature of around 100°C. The melting point is sharply defined. This means that the coating can easily slide over hot surfaces without sticking. A typically acceptable lower sealing strength would be 250 g/m^2/25 mm seal width. With a film shrinkage temperature of 150°C, this would give a sealing range of 50°C. It is necessary to have some slip and anti-blocking compounds incorporated in the coating to achieve the best packaging machine runnability. The coating weight is generally about 1.0 μm, and with a specific gravity close to 1, this gives a thickness of 1 μm.

7.4.3 PVdC coatings

PVdC coatings may be modified to produce either a good heat-sealing polymer or a high-barrier polymer. There is a compromise to be made between the quality of sealing and the barrier properties required. Modification of the polymer to give a wider sealing range lowers the threshold for sealing to around 110°C at the expense of the gas barrier. PVdC coatings are applied to films and paper.

The majority of general-purpose coatings supplied will have sealing properties starting to seal at 120°C and oxygen barrier of around 25 mL/m^2/24 hours. For PET film, PVdC is normally chosen for high oxygen barrier (10 mL/m^2/24 hours) and as a result may have poor sealing properties.

The formulation needs to incorporate both silica and waxes as slip and antiblocking agents to prevent the coatings from sticking to the hot sealing surfaces. Typically, film producers apply coating weights of 3 g/m^2 or 2 μm thickness. The specific gravity of PVdC is 1.3. Surface coatings can be applied to rigid containers, such as the surface of PET beer bottles.

7.4.4 PVOH coatings

With the environmental concern that dioxins may be produced if chlorine-based compounds are incinerated, an alternative high gas barrier has been sought to replace PVdC without needing to modify coating parameters. PVOH emulsions meet this requirement, but they are sensitive to moisture, losing barrier properties if the RH increases to more than 65% RH. Films with PVOH are, therefore, likely to be used as part of a laminate, with the PVOH on the inside of the web. BOPP with PVOH on the outside can be used, provided it is over lacquered with a protective varnish. PVOH also has no sealing properties. It is, however, an excellent surface to receive printing inks with low absorption or retention of solvents. Coating weights are similar to PVdC, but the specific gravity is nearer to 1.0 and film yield is slightly higher.

7.4.5 Low-temperature sealing coatings (LTSCs)

LTSCs for OPP that seal at lower temperatures and have a wider sealing range are required to meet the demand for faster packaging machine speeds. These coatings, based on ionomer resins, applied in the form of emulsions are an alternative to both acrylic and PVdC coatings. As silica and waxes are likely to raise the sealing temperature threshold of any coatings, they are kept to a minimum with the consequence that friction is higher on LTSC than with the conventional coatings. The LTSC does not stick or block to PVdC or acrylic coatings and, hence, it is possible to have differentially coated films. The ionomer surface has good ink receptivity and does not retain printing ink solvents.

7.4.6 Metallising with aluminium

Direct vacuum metallising with alumium on plastic films results in a significant increase in barrier properties. This is because these films are smooth and a continuous layer of even thickness can be applied. Films treated in this way are PET, PA and OPP. A major cost factor is the time taken to apply the vacuum after a reel change. This favours 12 μm PET because a large area can be contained in a reel. When applied to PET, the film can be used to metallise paper and paperboard by transfer from the film using a heated nip roll, after which the PET can be reused (Fig. 7.13).

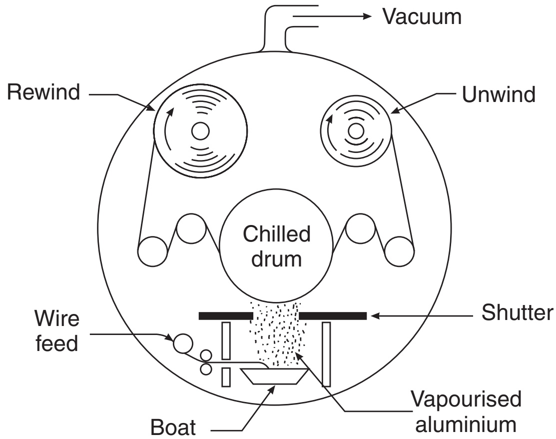

Fig. 7.13 Metallising process. (Courtesy of The Packaging Society.)

7.4.7 SiOx coatings

SiOx has been introduced as a coating. This material has excellent barrier properties. It is applied by vacuum deposition. SiOx coated PET film is commercially available and is used in the retort pouch laminates in Japan. It is transparent, retortable, recyclable and has excellent barrier properties. An alternative method of coating, Ceramis®, is operated by AMCOR in Switzerland which uses plasma pre-treatment followed by evaporation of the silicon using an electron beam (EB) (AMCOR Lohwasser, 2010). The coated films have excellent barrier properties and a high mechanical resistance.

SiOx has also been applied to plastic bottles, giving an oxygen barrier that is 20 times greater than the barrier of an uncoated bottle (Matsuoka *et al.*, 2002). The Glaskin process introduced by Tetrapak also vacuum coats the inside of PET beer bottles. Bottles coated in this way have been used by several leading breweries in Europe (Anon, 2000b, 2000c). Less flavour scalping has been claimed to result in a minimum shelf life of 6 months. The European use of thermal or EB chemical vapour deposition of silicon oxide and the reactive evaporation of aluminium is discussed in Naegeli and Lowhesser (2001).

7.4.8 DLC (Diamond-like coating)

A relatively new coating is known as DLC (diamond-like coating). It comprises a very thin layer of carbon. PET bottles do not give as long a shelf life as glass for the bottled beer market. A DLC coating on the inside of PET bottles has been trialled extensively in Japan. Significant improvements in barrier have been reported (Ayshford, 1998; Anon, 2000a).

7.4.9 Extrusion coating with PE

A heat seal coating can be applied to a heat-resistant film, such as PET and PA by extrusion coating the film with PE (Fig. 7.14).

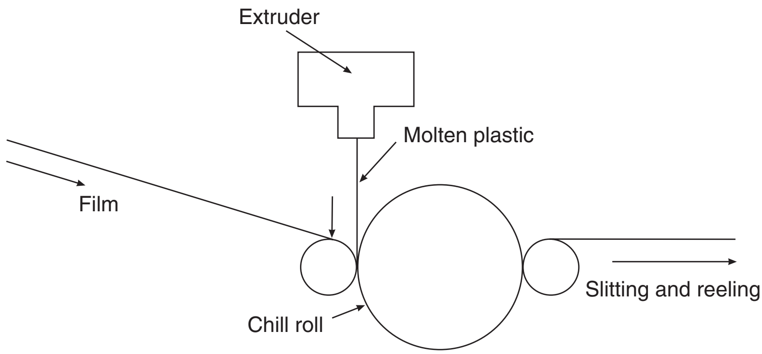

Fig. 7.14 Extrusion coating of plastic film.

7.5 SECONDARY CONVERSION TECHNIQUES

7.5.1 Film lamination by adhesive

The lamination of plastic films combines two or more films using an adhesive that can be water, solvent or 100% solids based. Lamination is an alternative to co-extrusion, where two or more layers of molten plastic are combined during film manufacture. It is also possible to laminate, using molten polymer as both an adhesive and a barrier layer in an extrusion lamination. It is also possible to laminate without an adhesive, e.g. laser lamination of thermoplastics.

The choice as to whether to use a laminate or a co-extrusion can be quite complicated, depending on several factors. These include the following:

- product needs, in terms of shelf life and barrier properties
- type of pack, how it will be handled at every stage and the run length
- waste during co-extruded film manufacture cannot be recycled whereas waste produced during single film manufacture can be recycled
- co-extruded film can only be surface printed, whereas one of the films in a laminate may be reverse printed so that the print can be sandwiched during lamination. This ensures rub resistance, gloss and clarity, dependent on the film concerned
- converters may print and laminate in one cost-effective operation; where this is not possible, the cost increase due to the extra conversion process may be difficult to justify. However, the cost of any alternative approach to providing the protection required by the product, either by a single plastic material or by a form of co-extrusion, must also be considered
- film thickness to achieve the required barrier must be considered in case it would be thicker than ideal, with increased stiffness giving sealing problems and handling difficulties. Sealing range may be narrowed due to poor thermal transfer, and heat retention after the seal has been made may allow seals to re-open
- on the other hand, a thicker material will be stiffer so that it handles and displays better than packaging made from a thinner material
- lamination will almost always highlight the different tension in each film web, and it is very common for laminates to suffer from curling. For many applications where the film is cut and then pushed or pulled, the cut edge may need to be flat to give trouble-free feeding through the packaging machine

There is a vast amount of literature published about laminating and co-extrusion. Consideration of what approach to take must be assessed on a case by case basis as there are both technical and commercial factors to be considered (Haas, 1996).

A wide range of adhesives are available. PVA and other water-based adhesives that remain flexible and have a long shelf life may not adhere satisfactorily to polyolefins (PE and PP) with their inert surfaces and excellent moisture barrier. Should such adhesives be used, then a long drying period is required before the laminate can be used and, in practice, paper or paperboard should be one of the substrates to allow the water to disperse.

Polyurethanes and other cross-linking adhesives are preferred for barrier plastics. They are normally applied from a gravure roller at the end of the printing press and the films combined under pressure, using a coating weight of 1–3 g/m^2. Careful selection is essential, as carbon dioxide can form as small bubbles and impair the visual properties of the final laminate. In some film structures, there is the possibility of the adhesive reacting with the film coatings to produce discolouration. When this happens, advice should be sought from the adhesive and ink suppliers. Adhesion strength of several hundreds of grams/25 mm is normal and often the bonding is permanent.

There is pressure to move away from adhesive systems based on the use of organic solvents to water-based and 100% solids systems to reduce solvent emissions. The 100% solids adhesives are materials that cross-link as a result of applied heat, UV or EB radiation. Tacky hot melt adhesives with a wax and EVA content and the use of PE in extrusion laminating would also be considered 100% solids adhesives.

With the increasing speed of printing, it has become common to operate a two-stage process of printing followed by lamination. This allows better control of the processing as the systems are independent.

7.5.2 Extrusion lamination

One web of a laminate can be passed through a curtain of molten PE and then combined with a second film layer whilst the PE is still molten. It is possible to use a small weight of PE (typically 7–10 g/m^2) as both an adhesive and as a means of making a laminate much stiffer due to the increased thickness of the total structure. There is often a need to prime the surfaces of the films to receive the PE and to achieve bond strengths above 200 g/25 mm^2 (Fig. 7.15).

For many applications where the laminate structure does not experience high stresses, the strength of a laminate may in practice only need to be about 100 g/25 mm at the lowest. The danger is always that the laminate bond may reduce with time, and hence the specification has to be set higher than the known minimum requirement.

7.5.3 Thermal lamination

When two webs each have heat-sealing properties, it is possible to join them together by passing the films through a heated nip roller system. With no adhesive involved, the final weight of the laminate is the same as that of the original components. This process relies on the films each having a low sealing point, as under tension the films may shrink if heated at a high temperature, causing creasing, or stretch under tension. As the films approach the elastic limit, curl may be produced due to the slightly greater shrinkage of one web. Bond strengths should be high depending on the nature of the original coatings. This form of laminating is not common for the production of laminates in the food industry. It is widely used in book cover production. A

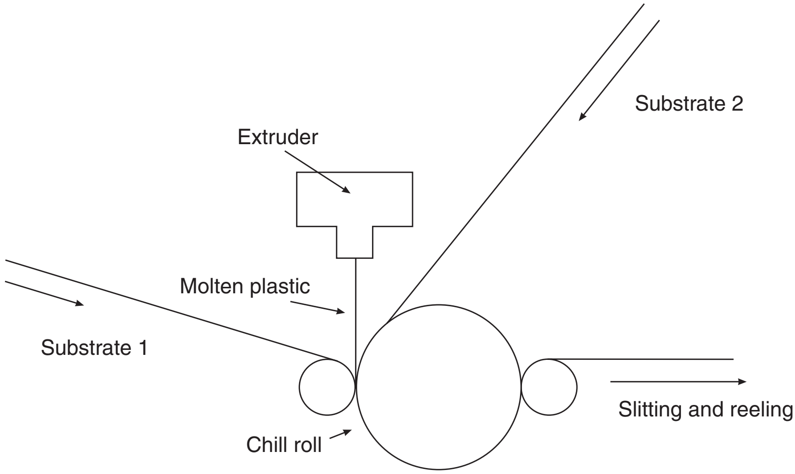

Fig. 7.15 Extrusion lamination.

specific type of thermal lamination is that using a laser to activate the surfaces being bonded (Potente *et al.*, 1995).

7.6 PRINTING

7.6.1 Introduction to the printing of plastic films

Printing preferences until recently seemed to be geographical, with a tendency for gravure presses being popular in Europe and flexographic presses in North America. This may be historical, as the result of the way the markets developed. As the quality of flexo printing has increased with the introduction of photopolymer plates and with the market requiring shorter and shorter print runs, the flexo process has gained ground in Europe. Combination presses that incorporate flexo and gravure units have also become popular. The number of printing stations has grown in number with up to 10 stations now available on central impression flexographic (CI) machines and on gravure reel fed presses.

7.6.2 Gravure printing

The gravure press consists of a series of printing stations in-line, each applying one colour of liquid ink, applying cold seal latex or PVdC emulsion in-line. A roller is engraved, mechanically, chemically or electrically laser eroded, into a pattern of small cells. These cells hold the ink that is picked up from the ink bath in which the gravure roller rotates. The amount of ink is controlled by the depth and area of the cell, and a doctor blade scrapes off the excess ink. Film is passed over the gravure roller with backing pressure from a lay-on, or impression roll, to pull the ink out of the cells. The inked film is passed into a heated oven to dry off the solvents or water medium. Other ink, or coating, layers are applied in register to achieve the finished design.

The gravure system allows a very large number of prints as the cylinders are hard wearing and accurately reproduce the design. Initial costs are high due to the engraving process, but, for long runs, which can be printed at high speed, the gravure process is cost effective.

7.6.3 Flexographic printing

Flexographic printing may be carried out with a number of printing stations in-line (stack press) or with the printing rollers arranged around a central large diameter drum (central impression). The plates that are now made from a photochemical (plastic) plate material are attached to the printing rolls. Ink is picked up by a cavitated anilox roll and transferred to the printing plate. The ink is then transferred to the film. Because the costs of producing the plates are relatively low, flexographic printing is cost effective, especially for short runs. The quality of reproduction has increased, and has approached that of gravure printing. Productivity on both types of press has increased, and hence the better choice of process for any given print order has become more difficult.

7.6.4 Digital printing

Electronic printing systems have been developed, and with coatings available to receive the new ink systems, it is now possible to create artwork on a computer and transfer the image directly to the packaging film. A design is created on a computer; it may be an individual design or replicated to give several hundreds of impressions. The ink, usually in powder form, is attracted on to the film surface and cured in place. Special coatings are necessary to receive the ink. A standard heat-sealable coating on the reverse side allows the film to be made immediately into packages. The system as yet is only suitable for narrow web widths and is capable of producing test packages for market research or promotional campaigns.

7.7 PRINTING AND LABELLING OF RIGID PLASTIC CONTAINERS

7.7.1 In-mould labelling

Printed labels can be applied to containers and lids during forming. The technique has been adapted for use in thermoforming, e.g. yoghurt pots, and in both blow moulding and injection moulding, e.g. ice cream tubs, lids and large biscuit containers.

Designs in relief can be carried in the walls of the mould. These designs are visible in the moulded item having an embossed or debossed effect. This technique is used to imprint the plastic identification for sorting in waste management schemes, indicate the number of the mould and other manufacturers' markings.

7.7.2 Labelling

Several types of printed labelling are common – pressure-sensitive plastic, paper and laminated aluminium foil labels. Sleeve labels are clipped or fixed with adhesive around pots and tubs. Such containers may require features, such as a recessed panel, in their design to facilitate the location of the label. Some packs are designed so that after use a paperboard label and plastic pot may be easily separated to meet waste management needs.

Another popular form of labelling of bottles and jars is the printed plastic shrink sleeve. These are supplied flat and printed in tubular form on reels. After automatic application, the container passes into a heated zone that causes the label to shrink tightly around the container.

7.7.3 Dry offset printing

This method uses a relief plate that after inking transfers the ink to a blanket roll, which in turn applies the design to the plastic surface. This method has especially been developed to print round and tapered containers. The inks are either heat set or UV cured.

7.7.4 Silk screen printing

The design to be printed is carried on a metal or plastic woven mesh. This is placed in contact with the item to be printed, and the thick oil-based ink is forced, or squeezed, through in the design areas with the action of a flexible wiping blade.

7.7.5 Heat transfer printing

The full design is first printed with heat-sensitive inks on a carrier web of PET. This can then be placed in contact with plastic containers at high speed where a heated die transfers the design directly onto the container. Therimage is an example of a well-known form of heat transfer labelling.

Hot foil stamping is a type of heat transfer printing. A heat-resistant ink with an adhesive coating carried on a PET film is placed in contact with the item being printed. A heated metal die with the design in relief is pressed against the PET film, transferring the image. This type of decoration can be used to print a highly reflective metallic image. Hot foil stamping is often used on luxury items, such as cartons for chocolate confectionery and labels for bottles of spirits and liqueurs.

7.8 FOOD CONTACT AND BARRIER PROPERTIES

7.8.1 The issues

In addition to the maintenance of pack integrity, i.e. efficient closure systems and physical protection during storage and distribution, it is essential that primary food packaging protects the food in such a way that health is not endangered and that the quality is maintained within the expected shelf life. Quality in this context depends on the packaging, the food product and possible interactions between the food and the packaging material. The result may be that detrimental organoleptic and other changes occur, which may be caused by:

- migration of additives, residues and monomer molecules from the packaging material into the food
- permeation of gases, vapours and permeant molecules from the environment into the pack headspace and vice versa
- sorption of components, including volatile flavour compounds and lipids, into the packaging in a process often referred to as scalping

7.8.2 Migration

When food products are packaged, the food is in direct contact with the inside surface of the packaging. It is possible for interaction between the food and the packaging to occur and for components of the packaging to be absorbed by, or react with, the food. In the case of plastic materials, this may involve the basic polymer, and even if this is non-reactive with respect to the ingredients of the food, it is possible that coatings and additives used to facilitate manufacture and use of the plastic may interact with the food. It is, therefore, essential that the plastic material and associated additives are approved for direct food contact.

To ensure that adequate product safety procedures are carried out, many countries have regulations to maintain safety with respect to plastics in contact with food. In the United States, the regulations emanate from the Federal Food and Drugs Administration.

In the European Union, Regulation (EC) No 1935/2004 is a Framework Regulation concerning the general requirements for all materials and articles in contact with food. The aim is to ensure that they are manufactured in accordance with good practice and that they do not transfer any constituents into food in such a way as to endanger public health or bring about organoleptic or other unacceptable changes in the nature, substance or quality of the food.

Organoleptic in this context refers to the taste, texture, flavour, colour or odour of the food product, and migration is the process whereby chemical components in the packaging material transfer into a food product.

In the European Union, EU Directive 2002/72/EC and subsequent amendment 2008/39/EC deal specifically with the use of plastics in contact with food, see website reference. It includes definitions and migration limits, provides a positive list of authorised monomers and a list of authorised additives and limits the use of residues associated with specific substances. A migration limit is either defined in terms of weight released per unit area, e.g. 10 mg/dm^2, or where this is either not feasible, e.g. for caps, gaskets, stoppers, or where the volume of the container is from 0.5 to 10 L, the limit is 60 mg/kg of the foodstuff concerned.

Directive 82/711/EEC sets rules for migration testing using specified food simulants, i.e.:

- simulant A: water for aqueous foods
- simulant B: 3% w/v acetic acid for acidic foods
- simulant C: 15% v/v ethanol for alcoholic products
- simulant D: rectified olive oil for fatty/oily foods

Sophisticated analytical and measurement techniques have been developed to identify and quantify the materials extracted by these techniques. They include the use of GLC (gas liquid chromatography), mass spectrometry and IR analysis. These test procedures are also used, together with sensory testing panels, to evaluate plastic materials and packaging in production and use (Frank *et al.*, 2001).

7.8.3 Permeation

Permeation through a film is a three-part process:

1. Solution/absorption of penetrant (vapour or gas) into the polymer surface.
2. Migration/diffusion of penetrant through polymer(s).
3. Emergence/desorption of penetrant from opposite surface of polymer.

Absorption and desorption depend on the solubility of the permeant, and solubility is greatest when penetrant and material have similar properties. Other relevant theory comprises the following:

- Graham's Law (1833), which states that the velocity of diffusion of a gas is inversely proportional to the square root of the density
- Fick (1855) stated that the quantity of diffusing gas is proportional to concentration and time and inversely proportional to the thickness of the substrate through which it is diffusing
- Henry's Law (1803), which states that the amount of gas absorbed by a given volume of a liquid at a given temperature is directly proportional to the partial pressure of the gas

In practice, the film may comprise more than a single polymer, and there may be discontinuities in coatings, pinholes in films, variations in molecular structure and degree of crystallinity. The penetrant molecular size, shape and degree of polarity are relevant and so are ambient conditions. These are all factors that affect diffusion and solubility, which in turn have a direct impact on permeability.

The permeability of plastic films to moisture vapour and common gases such as oxygen, carbon dioxide and nitrogen, has been measured by standardised test methods. Oxygen, for example, can cause oxidative rancidity in oil or fat containing food products.

Water vapour permeation into a product may cause a loss of texture, and, on the other hand, the escape of water, in the vapour phase, from a product through the packaging may cause dehydration, textural changes and loss of weight. An example of the latter would be a plastic film-wrapped Christmas pudding that would lose moisture in storage prior to sale, where a compromise has to be made in balancing weight loss in storage with initial weight and the water vapour barrier protection provided by the plastic film. In this example, in addition to flavour retention and texture, the actual weight at the point of sale would also have to meet appropriate regulations.

The results of permeability tests provide guidance with respect to the choice of material(s) for the packaging of specific food products. Some other possible penetrants and the effect of the presence of polymer additives, e.g. plasticisers, can lead to surprising results. It is still necessary to carry out shelf-life tests to establish performance in practice with the food under consideration.

7.8.4 Changes in flavour

Food manufacturers have to ensure hygiene and freedom from odour and taint in their products. This has implications for the packaging used, in the sense that contaminating material from the external environment must be prevented from changing the flavour, aroma or taste of the food. An example would be the use of PVdC coated BOPP film to overwrap cartons containing tea bags.

Flavour may be lost by scalping. This is where organic compounds are absorbed into the packaging or adsorbed on the surface of the packaging material. Flavour may be masked or chemically changed by any ingress of off flavours and aromas from the external environment by permeation (transmission) through, or by migration of contaminating ingredients from, the packaging material.

Food may also be changed by the loss or gain of moisture and by oxidation. Hence, the permeability of the packaging material to the transmission of moisture vapour and oxygen is an important property of the packaging material. The rate of transmission is dependent on the ambient temperature and the principles of premeation. In addition to the qualitative and quantitative tests referred to in section 7.8.2 subjective assessment of flavour, odour and taint is carried out by statistically valid sensory testing panels.

7.9 SEALABILITY AND CLOSURE

7.9.1 Introduction to sealability and closure

The most important function of packaging is to ensure the protection and integrity of the product. This implies that the pack must be securely sealed. With plastic packaging, this can be achieved on the packing line by either heat sealing, application of a closure, such as a screw cap, or by the use of some form of adhesive system.

One of the most overlooked factors in the production line is the efficient performance of the packaging system. Sealing or closing systems are often presumed to perform with little consideration of the material/machine relationship.

The needs of the proposed material or container are seldom discussed with the machinery manufacturer. At the earliest stage therefore, planning needs to take place between production, engineering, purchasing, product R&D, marketing and packaging technologists with machinery and packaging suppliers. It may be found that compromises will have to be made to find the optimum solution.

7.9.2 Heat sealing

Product protection and hence effective shelf life are a function of the quality of sealing of the package. Sealing strength is influenced by the thickness of the film web. With the same coating, a doubling of the base film thickness almost doubles the seal strength. Conflictingly, the thicker the material, the narrower the temperature sealing range under normal sealing conditions. The thicker film does not allow heat to flow so easily to melt the sealing coating or polymer, and when heated, the film retains the heat, allowing the sealant to remain fluid, with a detrimental effect on hot seal strength. Thick film also requires more pressure to bend the film and make intimate contact, particularly with crimp jaws, as found on f/f/s machines.

Jaw design has a great influence on seal integrity and strength. While the ideal seal jaw may be flat, in practice this is only true if there are no folds or tucks in the seals. Crimp jaws are used to compensate for variations in film thickness on vertical and horizontal f/f/s machines.

Seal integrity may now be evaluated as part of the in-line quality function by using standard instruments to test the pack under pressure or vacuum and identify how quickly air or oxygen will pass through the seals. A practical judgement has to be made on the time and pressure required to change the pack integrity.

7.9.3 Flat jaw sealing

Sealing conditions are a compromise between dwell time and the temperature and pressure of the jaws. The requirement is to apply sufficient energy to cause the sealant to fuse together and become one medium. Conduction of heat, combined with heat flow characteristics, needs to be carefully balanced to produce a perfectly formed seal, with no temperature distortion and an even seal strength throughout the sealed area. Energy input is a function of time and temperature. With heat-sensitive films, such as PE and cast PP, a low temperature applied for a long period, with high pressure to remove air from between the film surfaces, is ideal. With films having a wide temperature-sealing range, the tolerance in dwell time, sealing temperature and pressure is much wider.

If possible, heat should be applied to both sides to achieve the quickest possible polymer melting. Sealing surfaces need to have good release properties to ensure that molten polymer does not stick to the heating surfaces and pull the newly made seal apart. An alternative is to use one heated surface in the form of a constant temperature metal bar, with a flat or curved profile, sealing against a rubber-faced anvil.

With PE, there is a need to avoid stressing the seal while the polymer is still fluid and many machines are designed to have an air cooling blast or, alternatively, clamping of the seal whilst the film cools below the sealing temperature. With OPP films where the core of the film is not being melted, an effective seal is achieved by fusing sealant polymers of co-extruded film or two surface coatings that flow together. The core will give rigidity to the seal, and to avoid destroying the new seal, it is only necessary to ensure that fluid coatings are not stressed. Pulling jaws apart at a perpendicular to the film overcomes the problem in practice. Film sliding over hot metal while under pressure is to be avoided as the coating may stick to the metal surface. If it is impossible to avoid the film sliding over metal under pressure, the solution is often to ensure that only point contact is made between the heated metal and the film. A rough surface minimises or avoids hot-sticking on the machine. The principle is to avoid total air exclusion between the contact surfaces, which may be caused by the coatings flowing freely, creating a vacuum. Highly polished sealing surfaces are to be avoided. This seems contrary to the normal practice of polishing surfaces to make them more slippery but has been found to be the case on many machines.

Good film formulation with a balance of slip agents in the coating should minimise or avoid hot stick problems, whilst not affecting the sealing performance.

Accurate control of jaw temperature is important, particularly where the temperature sealing range is low and close to the melting point of an oriented film.

When a plastic film, such as PVdC coated OPP, is being used to overwrap a carton, it is only possible to use one heated surface, and the pressure necessary during sealing is provided by the rigidity of the carton. Precise jaw temperature control is essential to ensure that the envelope-shaped end folds of the film do not shrink during sealing and thereby become wrinkled and unsightly.

7.9.4 Crimp jaw conditions

Specific plastic film materials should, ideally, have a unique crimp jaw specification for each thickness, but a compromise is always needed as machines have to handle a wide range of films without modification or resetting mechanical parameters. As different thickness films keep crimp jaws apart by differing amounts, the loads on the crimp jaw slopes vary, and this is shown in the distortion or variability of the seal performance. Crimp jaws should be set to the ideal distance apart and spring pressures or loadings established when the crimp jaws are hot, at temperatures close to the preferred sealing temperature.

Only then should knives be set to cut through the films. Stenter-made PP films have greater extensibility in the MD, typically greater than 150% elongation before break and 70% in the transverse direction (TD). Form/fill/sealing (f/f/s) machines perform better and give better seal integrity with transverse jaw grooves to minimise stress in the TD and allow more extension in the MD.

It is seen that opaque cavitated Stenter-made films have a greater tendency to split across the film in crimp jaws that stress the films beyond their elastic limit. The film does not elongate as well in the TD as in the MD, and hence shallower angled jaws with an angle of 120° and sinusoidal profile have been developed to minimise the stress.

These designs conflict with blown (bubble) oriented films where extensibility is closer to 100% in each direction. Conditions of high pressure and the lower heat stability of bubble-made OPP will still give the same effect at the high end of sealing conditions.

PET and nylon PA films with their superior heat stability giving very wide sealing ranges do not normally develop split seals. Using PE or cast PP as the sealant of a laminate exploits the easy flow nature of cast and low-melting point polymers. The molten polymer can flow into crevices and fill any gaps or holes in the seal. While satisfactory for many pouches, the inability of the laminates to seal inside to outside layers limits the application to f/f/s with fin seals, as compared with overlapping seals, along the length, and this uses slightly more material because of the extra width of film required.

The ionomer emulsions used as coatings with low melting points of around 80°C and a high level of hot tack have extended the sealing range of coated OPP to over 70°C, where the upper sealing limit is set by the shrinkage of the film, judged to be 150°C. Formally, acrylic-coated films had the widest range of 50°C with the starting point at 100°C, and this enabled linear packaging speeds of 50 m/min to be achieved. With high packaging speeds, it is normal to have high temperatures to melt the sealant in a very short dwell time. When the machine speed varies, the high temperature of the sealing jaws damages the film. With the LTS (low temperature sealing) coating, lower heat settings are possible, thus avoiding film damage at slower speeds. Such low sealing threshold temperatures mean that a very short dwell sealing time is possible at lower temperatures with crimp jaws, thus avoiding film shrinkage. In effect, the amount of energy required to make a seal is much lower than with other coatings, and film speeds of 100 m/min may be achieved. LTS coatings will not seal to other mediums and so only f/f/s applications can be utilised, which seal inside to inside, i.e. fin seals.

Most seals are considered to be strong enough if the film tears when the seal is stressed. Seals provide built-in evidence of tampering, but the packs may still be opened easily, especially in the case of oriented films with their easy tear propagation properties. However, there is a school of thought that argues that if the seal peels open slightly and absorbs the stress without tearing, then the pack is still intact and continues to function. Tamper evidence in this case is less obvious.

In all cases of packaging small and low weight products using films/coatings that do not flow too readily during sealing, a minimum seal strength requirement of 300 g/25 mm is typical. Heavier product weights and free-flowing products, such as nuts, rice, pulses and frozen vegetables may have to have seal strengths in excess of 1000 g/25 mm.

7.9.5 Impulse sealing

With impulse sealing, jaws are heated to fusion temperature by a short powerful electric impulse. The seal area remains clamped and is cooled under pressure. Impulse seals are generally narrower than hot bar seals but can be doubled up. When minor contamination is present, the impulse method may give a better seal. Voltage and duration are varied according to the material.

PE films may be sealed with impulse-heated wires or strips to make welded seals. If the seal is not to be cut through the web, the heating strip has to be covered to protect the molten polymer from sticking to the heated metal strip and destroying the seal. This is achieved by covering the strip with a release sheet, such as PTFE-covered glass fibre woven cloth. The resultant seals achieve 100% film strength. It is possible to make the same type of seals with co-extruded OPP, using PE sealing equipment, but the seals are more sensitive to tearing close to the seal due to the normal easy tear propagation caused by high stress orientation.

7.9.6 Hot wheel sealing

In this form of heat sealing, the material to be sealed is drawn past a hot wheel. The seal area is kept under pressure until it cools and a seal has developed.

7.9.7 Hot air sealers

This uses hot air, heated by gas or electricity, to melt the plastic in the seal area. It is used for the sealing of plastic-coated paperboard.

7.9.8 Gas flame sealers

This form of sealing uses gas flames to melt the plastic in the heat seal area. It has a lower noise level and is more heat efficient than hot air sealing.

7.9.9 Induction sealing

A common form of induction sealing is that which is used to heat seal a diaphragm, incorporating a plastic or plastic-based heat-sealing layer, laminated or coated onto aluminium foil, already in place in the closure, to the rim of a plastic, or glass, jar or bottle. The closure is applied to the container and passed under a high-frequency induction sealing head that generates heat in the aluminium foil, which then melts the plastic and heat seals it to the perimeter of the container.

7.9.10 Ultrasonic sealing

This is similar to high-frequency induction heating, except that the heat is generated by molecular friction in the plastic material itself. This principle has been used to seal the corners of plastic-coated paperboard trays.

7.9.11 Cold seal

As already stated, sealing conditions are a balance of time, temperature and pressure. Where high-speed packing is required and the product is heat sensitive, such as a chocolate countline bar or chocolate-coated ice cream, the first choice sealant is cold seal latex. The adhesive is converter applied in a pattern on the reverse side where the seals are to be made, accurately registered with the print on the outside. This specification requires a release lacquer over the print on a single web film, or a release film laminated as the outer layer of a laminate.

7.9.12 Plastic closures for bottles, jars and tubs

In food packaging, the most common form of screw cap is injection moulded using PP. Where a flexible snap-on feature is required, as for instance with an ice cream tub, or as a reclosure after opening a long shelf-life pack, PE is preferred. PE is used for plastic wine bottle corks.

The hinge property of PP has been made use of as a closure, which remains in contact with the container. A wide variety of designs are applied to containers for products that are dispensed from the container, such as salt, pepper, spices and herbs.

Another thermoplastic used for closures is PS, which is harder and glossier than PP. The tightest tolerance, dimensionally, is provided by thermosetting plastic closures, though these are more commonly used for pharmaceutical and cosmetic closures. Most plastic closures can have a tamper-evident feature incorporated in the design.

7.9.13 Adhesive systems used with plastics

Most forms of adhesive can be used with plastics, for example:

- a tie or grafting layer of plastic used to promote adhesion in extrusion coating and co-extrusions
- dry bond adhesives used for laminations involving plastic substrates from which solvent is evaporated prior to bonding the surfaces together
- heat curing adhesives used for lamination, which are 100% solids, operate by cross linking to the solid state once the lamination has been completed
- hot melt adhesives, which include plastic components, for applying labels
- hot melt adhesives used to erect and close folding cartons on packing lines
- PVA water-based adhesives for side-seam-sealing folding cartons during conversion, including cartons made from one-side PE-coated paperboard, where the PE has been corona discharge treated
- pressure-sensitive and heat set label systems

7.10 HOW TO CHOOSE

The key to successful food packaging is to identify the packaging needs of the product. These relate to the nature of the product, the intended market, shelf life, distribution and storage, point of sale to the ultimate consumer and the use and eventual disposal of the packaging. The choice should take account of environmental and waste management issues. Ensuring food safety with respect to biological risks and needs relating to flavour, colour and texture is essential.

Packaging needs can be considered in terms of:

- protection of the product – quality, safety, etc
- appearance – sales promotion, pack design, etc
- production – extrusion, forming, printing, packing, etc

Having decided that a type of plastic pack selected from the range of possible choices, such as a film sachet, lidded tray, bottle, etc., the next decision concerns the type of plastic or combination of plastics necessary to meet the functional needs. Performance is related to the structural design of the pack and whether it is made from film, sheet, moulding or expanded plastic. As we have

Table 7.1 Ranking of various films with respect to specified properties.

Polymer	Water vapour transmission rate (WVTR)	Gas permeability	Optics	Machine performance	Sealing
LDPE	3	4	4	4	1
Cast PP	3	4	2	4	2
OPP	2	2	2	2	2
OPP coated	1	1	1	2	1
PET	2	2	1	1	4
PVC (plasticised)	3	2	2	4	2

1, excellent; 2, very good; 3, Good; 4, Poor.

seen, there are many plastics, each offering a range of properties, and within each packaging type there are differences.

All plastics provide barriers to the ingress of gaseous and volatile materials from the external environment into a hermetically sealed pack and from the food product both into and through the pack into the external environment.

The extent to which these effects occur will depend on the food product and on the type of plastic(s), its thickness and on the temperature and RH ranges to be experienced during the life of the product.

Some plastics are heat sealable so that packs can be sealed; some are also heat resistant to meet defined needs, e.g. reheating by microwave, radiant heat and retort sterilisation. Some are suitable for storage in deep freeze. Many specific needs can be met within the defined conditions of use.

In a chapter of this type, we can make readers aware of the choices and provide a basis for meaningful discussions between technologists whether they be suppliers or users of plastic packaging. Tables 7.1, 7.2, and 7.3 give some guidance in terms of ranking for moisture vapour permeability, gas permeability, optical properties, packing machine performance and heat sealability.

Table 7.2 General gas and moisture barrier properties.

Film (25 μm thickness)	Water vapour transmission rate (WVTR)	Oxygen transmission rate
LDPE	10–20	6500–8500
HDPE	7–10	1600–2000
OPP	5–7	2000–2500
Cast PP	10–12	3500–4500
EVOH	1000	0.5
PVdC	0.5–1.0	2–4
PA	300–400	50–75
PS	70–150	4500–6000
PET	15–20	100–150
Aluminium	0	0

Units: WVTR in $g/m^2/24$ hours at tropical conditions of 90% RH at 38° and gas permeability in $cm^3/m/^2 24$ hours.

Table 7.3 Examples of suitability of various films for packing the products named.

Product	LDPE	OPP	OPP (metallised)	OPP (coated)	Laminate (no Al)	Laminate (+ Al)	Package type
Fresh bread	***	***	0	0	0	0	HFF
Longlife bread	0	0	*	*(MAP)	**(MAP)	**(MAP)	HFF
Snacks/crisps (chips)	0	*	***	***	**	***	VFF
Biscuits	0	0	**	***	**	***	HFF
Nuts	0	0	**(MAP)	*(MAP)	**(MAP)	***(MAP)	VFF
Cooked meat	0	0	*	**	**(MAP)	***(MAP)	Pouch
Frozen food	**	*	*	0	***	***	Various

0, not suitable; *, short life; **, medium life; ***, long life; MAP, modified atmosphere pack.

The commercial consideration of cost must also be considered. Run lengths and lead times are also important. It is not unknown for there to be run length cost differences, where at one point a particular solution is cost effective relative to an alternative solution and for the position to be reversed at a different run length.

7.11 RETORT POUCH

7.11.1 Packaging innovation

The retort pouch is discussed here as a demonstration, case study, of the integrated approach involving packaging materials, their conversion, forming, filling and sealing together with the processing and machinery that is necessary to establish any new form of product/packaging presentation. The retort pouch is a rectangular, flexible, laminated plastic, four-side hermetically sealed pouch in which food is thermally processed. It is a lightweight, high-quality, durable, convenient and shelf stable pack. Foods packed and processed in retort pouches are in successful commercial use for a wide variety of foodstuffs in several countries, particularly Japan. They were originally developed in the 1950s and 1960s in America through research and encouragement from the US Army.

The materials from which retort pouches are made are either aluminium foil bearing/plastic laminates or foil-free plastic laminate films. These must be inert, heat sealable, dimensionally stable and heat resistant to at least 121°C for typical process times. They should have low oxygen and water vapour permeability, be physically strong and have good ageing properties (Table 7.4).

These laminates demonstrate a range of barrier properties against oxygen and moisture vapour. Those without aluminium foil are transparent. The outer polyester film provides strength and toughness, while the inner PP provides good heat-sealing properties, strength, flexibility and compatibility with all foodstuffs. The additional incorporation of an oriented PA (nylon) film layer further increases the durability of the pouch, especially where the individual pouches are not, subsequently, packed individually in cartons. AlOx (metallised) coatings are being used to improve barrier, and SiOx provides both high barrier and pack microwaveability. The layers are laminated to each other using specially developed thermo-stable, food compatible adhesives.

Typical thicknesses: PET 12 μm, PA 15–25 μm, Al foil 7–9 μm and CPP at 70–100 μm.

Pouches are reverse printed in a wide range of graphics on the PET film before lamination, so that the print cannot come into contact with the food. All laminates are required to meet very

Table 7.4 Typical current examples of retort pouches. (Adapted from Dai Nippon Printing Co. Ltd., 2010.)

Types	Properties
Aluminium type	
PET/Al/CPP	Used for small pouches sold in decorated boxes for curry, sauces, household dishes
PET/Orientated PA/Al/CPP	Strong pouches, widely used (small to 3 kg)
Transparent type	
PET/Orientated PA/CPP	Transparent type pouch rice, chilled hamburger steak vegetable, fish, dumplings
Transparent barrier type	
SiOx PET/Orientated PA/CPP	Highest barrier for transparent pouch
PET metallised Al/Orientated PA/CPP	Good transparency type (strip metallised)
Orientated PA/PVdC/CPP	Vacuum packaging
Orientated PA/EVOH/CPP	High barrier, appropriate for vacuum pkg.

stringent requirements to ensure no undesirable substances can be extracted into the packaged food.

7.11.2 Applications

Retort pouches are used in several countries for a wide range of processed shelf-stable products, from solid meat packs, such as polonies to sliced meat in gravy, high-quality entrees, fish, sauces, soups, vegetables, fruits, drinks and baked items. Current markets for pouches are:

- retail packs up to 450 g for home use and outdoor activities. Foil-free pouches have been utilised particularly for vegetables where high visibility is desirable and a short shelf life from 4 weeks to 6 months is acceptable. In these instances, oxygen permeability is the overriding factor in determining shelf life, although light is also important with regard to product browning and onset of rancidity
- self-standing pouches have been used for fruit juices and other drinks, soups and sauces
- large catering size pouches for the institutional trade up to a capacity of 3.5 kg, approximately equivalent to the A10 can, have found ready application for prepared vegetable products, such as carrots, peeled potatoes and potato chips. The relatively easier disposability of the pouch after use is also an advantage in the catering and institutional markets
- provision of military field rations

Reduced heat exposure offers an opportunity for using retort pouches to process heat-sensitive products not currently suited to canning, especially in high temperature/short-time processing where opportunities exist for optimum nutrient and flavour retention.

By far the biggest producer is Japan where production is approximately 1 billion pouches per annum. A wide variety of products are packed; curries, stews, hashes, prepared meats, fish in sauce, mixed vegetables, all being popular dishes. Several factors that contributed to the success of pouches in the Far East are:

- limited refrigeration facilities when these packs were introduced, particularly in homes, resulting in demand for ambient shelf stable products. With increased use of refrigerators lower barrier pouches are now being used for shorter shelf-life products in refrigerated storage
- social changes causing working housewives to look for convenience
- the popularity of foods, such as sauces, which are pumpable and ideal for pouches

In Europe and North America, by contrast, the present market is relatively small. Main applications are for products, such as rosti (fried grated potatoes), prepared meats, smoked sausage (frankfurters), smoked salmon, fish, pet food, entree dishes, vegetables and diced and sliced apples. Lack of market expansion is attributed to a highly developed frozen-food chain, the competitiveness of frozen foods of a similar type and highly automated, cost effective, canning facilities.

7.11.3 Advantages and disadvantages

The following advantages are claimed:

- less energy is required to manufacture pouches compared with cans
- transport of empty containers is cheaper (85% less space required than cans)
- packaging is cheaper than equivalent can and with carton cost is about the same
- filling lines are easily changed to a different size
- rapid heat penetration and faster process results in better nutrition/flavour
- contents are ambient shelf stable – no refrigeration is required
- packed pouch is more compact requiring about 10% less shelf space
- less brine or syrup used, pouches are lower in mass and cheaper to transport
- fast reheating of contents by immersion of pack in hot water. No pots to clean
- opens easily by tearing or cutting
- ideal for single portion packaging and serving size control
- retort pouch materials are non-corrosive
- convenient for outdoor leisure and military rations use

There are also some disadvantages, such as:

- to achieve equivalent cannery production efficiency, a major investment in new capital equipment for filling and processing is required
- production speed on single filler/sealer is usually less than half that of common can seamers
- new handling techniques have to be adopted and may be difficult to introduce
- heat processing is more critical and more complex
- to retain rapid heat penetration there are limitations on pouch dimensions
- some form of individual outer wrapping is usually required, adding to cost
- being non-rigid products, such as some fruits lose their shape
- being a new concept, education of the consumer as to correct storage and use is required during marketing

7.11.4 Production of pouches

Pouches can either be formed from reels of laminated material either on in-line form/fill/seal machines in the packer's plant or they may be obtained as preformed individual pouches sealed on three sides, cut and notched. Forming consists of folding the laminate material in the middle, polyester (or PA) side out, heat sealing the bottom and side seals and cutting to present a completed pouch. Alternatively, two webs can be joined, heat seal surfaces face to face, sealed, cut and separated. Hot bar sealing is the most common practice.

Notches are made in the side seal at the top or bottom to facilitate opening by the consumer. Modern pouches have cut rounded corners that reduce the possibility of perforation caused by pouch-to-pouch contact. Rounded corner seals can also be incorporated.

The four-seal flat shape and thin cross section of the pouch is designed to take advantage of rapid heat penetration during sterilisation and on reheating, prior to consumption, saving energy and providing convenience. The flat shape also enables ease of heat sealing and promotes high seal integrity. From a military point of view, the flat section is compatible with combat clothing without restricting the physical movements of the soldier.

Fin seal design and certain gusset features permit the design of upright standing pouches although they create multiple seal junctions with increased possibility of seal defects. Several of these upstanding pouches are, however, available commercially. A wide range is possible in the size and capacity of pouches.

Nominal thickness after filling varies from approximately 12 mm for a 200 g pouch to 33 mm for a 1 kg size. Some unused package volume must be allowed for, as good practice dictates no void/headspace within 40 mm of the pouch opening.

7.11.5 Filling and sealing

In-line and pre-made pouches are filled vertically. Vertical form/fill/seal machines can be used for liquid products. Another method employs a web of pouch material that is formed on a horizontal bed into several adjacent cavities.

The cavities are filled whilst the seal areas are shielded. This method is especially useful for filling placeable products. Thereafter, the filled cavities are simultaneously sealed from the top, using a second web fed from the reel. The essential requirements for filling are:

- the pouch should be cleanly presented and positively opened to the filling station; solids are filled first, followed by the liquid portion, usually at a second station
- matching fill-nozzle design and filler proportioning to the product
- non-drip nozzles
- shielding of the sealing surfaces
- bottom to top filling
- specification and control of weight consistent with the maximum pouch thickness requirement
- product consistency in formulation, temperature and viscosity
- de-aeration prior to filling

Seals and sealing machines, like fillers, are constantly being refined and speed has improved from 30 to 60 pouches per minute to the current production rate of 120–150 pouches per minute. Sealers incorporate either one of two common satisfactory sealing methods, namely hot bar and impulse sealing.

Both methods create a fused seal whilst the pouch material is clamped between opposing jaws, thereby welding the opposing seal surfaces by applying heat and pressure. Exact pouch-sealing conditions depend on the materials and machinery used, but monitoring of seal temperature, jaw pressure and dwell time is essential. Pouch closure is normally accompanied by some means of air removal, either by steam flushing or by drawing a vacuum in a sealed chamber or simply, in the case of liquid food products, flattening the pouch by squeezing between two vertical plates. Efficient air removal prevents ballooning and rupturing during retorting. Excess air can also adversely affect heat penetration. While some very limited condensate moisture may be tolerated, a seal area clear of contamination is essential. Irrespective of the method of pouch presentation to the sealing, station grippers engage on each side, stretching the pouch opening and preventing wrinkles. The closure sealing is then carried out. Cooling after the sealing is essential to prevent wrinkling of the seal area.

All seals, whether side, bottom or closure seals, must be regularly tested. Performance is the ultimate measure of a good seal and the performance standard is the hermetically sealed can. Seals can be examined visually and sample pouches should routinely be subjected to internal pressure resistance tests (280 kPa for 30 seconds) in a suitable test jig. Seals made in this way should not yield significantly. Satisfactory seal tensile properties should also be confirmed on 13 mm sections, regularly cut from the various seals. Visual inspections at best are never wholly successful. However, inspection of all pouches before and after retorting can ensure a low rate of defects. Channel leaks, product contamination and weak seals can be detected using an ultrasonic technique (Ozguler *et al.*, 1999).

7.11.6 Processing

Processing takes place in steam-heated pressure vessels or retorts. Special precautions are required to prevent unnecessary straining of the pouch seals. These involve the use of superimposed air pressure and trays that control pouch thickness. Overpressure counter balances internal pressure build-up in the pouch during processing. This is particularly essential towards the end of the cycle when cooling commences and product is at its hottest. Overpressure also provides some restraint on the pouch preventing agitation and movement of the pouch walls, which could strain the seals and limits, but cannot prevent expansion of vapour bubbles in the product. The heating system is provided by either of the following:

- steam-heated water with compressed air overpressure
- mixtures of steam and air

Limiting the amount of air in the pouch at the time of closure to the practical minimum is essential as it can affect heat penetration during processing. Instrumentation and control valve systems are vitally important to accurately control and record both pressure and temperature (within $+1°C$ and $-0.5°C$) during the retorting of pouches. Automatic process cycle control is preferred. Vertical retorts may be used but horizontal batch retorts are the most commonly used. Fully automatic units for steam/air processing have been developed in Japan to facilitate high temperature/short time processing at 135°C, and higher. This short time high temperature treatment offers opportunities for milk and dairy-based specialities.

Trays or racks should be constructed of non-corrosive material without sharp projections or rough surfaces. Whilst heat penetration into pouches is more rapid compared to similar capacity cans, small changes in pouch thickness can have a profound effect on the lethal value achieved during the thermal process. For example, a change in thickness of only 2 mm can result in a change of F_0 value (lethality of sterilisation) of 1.5 minutes. For this reason, pouch dimension (thickness) is positively controlled by specially designed trays or racks that enable the easy placement of pouches in individual compartments while providing, on stacking, predictable maximum pouch thickness. Tray design usually incorporates a false bottom and sufficient void area (40%) in the supporting surface to ensure maximum exposure of each pouch to the heating medium. The maximum diameter of voids in the supporting surface should be less than the size of solid product portions, which could cause slumping of the pouch surface into the holes, thus altering the maximum thickness of the pouch.

Horizontal pouch orientation is the most common as it allows the least strain on seals and favours a uniform section across the pouch surface. Vertical pouch orientation in racks is, however, also utilised. The only stipulation is that the system allows thickness control and unrestricted movement of the heating medium around each pouch. In batch systems, the trays are stacked on top of one another on trolleys. These are then pushed on rails into horizontal retorts. Several trolley loads are pushed into the retort before it is sealed. In continuous retort systems, pouch carriers or compartments are attached to conveyor chains that move through locks into and out of the processing section in much the same way as applies to cans. These carriers provide the same thickness control and exposure to the heating medium as mentioned above for batch retorts.

7.11.7 Process determination

Heat transfer is highly dependent on the conductivity of the food and the geometric shape of the container. Therefore, the well known General Method and the Formula Method of Ball (and subsequent modifications) for process determination for conventional cans apply equally to retort pouches. Consequently, Fo values suitable for canned products are adequate for the same product in pouches. The mathematical approach to process determination of heat transfer into the retort pouch is that of transfer into a thin slab rather than a finite cylinder, as in the case of the can. Whilst these standard mathematical approaches are of assistance in process design, they are not a substitute for full process determination by proper heat penetration or innoculated pack tests.

The process used for the retort pouch should be based on the maximum pouch thickness a particular racking system will accommodate, and deliberately include overfilled units of a degree likely to be encountered. It is always necessary in designing heat penetration tests to ensure that account is taken of the worst case and that test pouches are located in previously established slow heating points in any stack of trays. Information as to the uniformity of heat distribution in a particular retort must be established through heat distribution studies beforehand.

Ideally, temperature variations from point to point in a retort should not be greater than 1°C. Several repeats of the heat penetration determination are necessary to ensure that all variations of critical parameters likely to occur in production are taken into account. In addition to the above, it is a recommended practice to add a 10% safety factor to all process recommended settings.

7.11.8 Post retort handling

Following pressure cooling and removal in racks or trays from the retort, the pouches must be dried, inspected and placed in some form of outer packaging. Drying of pouches is achieved through a combination of pack residual temperature to encourage evaporation and a system of high velocity air knives in a drier to drive off the remaining water. When dry, pouch seals may once again be visually inspected for leaks, ruptures or weak points that have been shown up during retorting. This should not involve manual handling of the individual pouches. Systems are available for the transfer of the pouches from the retort racks to conveyor belts, thence to the pouch driers and onto inspection conveyors prior to secondary packaging.

7.11.9 Outer packaging

The secondary packaging of retort pouches for storage and distribution may either involve packing each pouch in a printed carton or, alternatively packing a number of pouches in a transit case, possibly incorporating vertical dividers. The recommendation of individual pouches in cartons is made to avoid the dangers of leaker spoilage due to external microbial contamination from the environment, workers or consumers. The practice in Japan and Europe suggests that the retail marketing of unwrapped or naked pouches is nonetheless possible without any apparent practical increase in spoilage. For US military field rations, a paperboard folder, or envelope, in which the individual pouch is glued, has been used. This allows for non-destructive visual inspection and reclosure, while the pouch exhibits greatly improved abuse resistance even under severe military use.

7.11.10 Quality assurance

A successful pouch packaging quality system requires:

- selection and continued monitoring of the most suitable laminate materials
- regular testing of formed pouches for seal strength, product resistance and freedom from taint
- careful selection, maintenance and control of filling, sealing, processing and handling machinery
- specifications for the control of product formulation, preparation (viscosity, aeration, fill temperature, etc.) and filling (ingoing mass and absence of seal contamination)
- post-sealing inspection and testing of closure seals to confirm fusion, absence of defects and contamination
- control of critical parameters influencing processing lethality, such as maximum pouch thickness and residual air content
- standardised retorting procedures applying only recommended process times and temperatures confirmed to achieve adequate lethality
- regular inspection and testing of retort equipment and controls to ensure uniform heat distribution
- visual inspection of all pouches to check sealing after processing
- handling only of dry pouches and packing into collective or individual outer packaging specially tested to provide adequate, subsequent, abuse resistance
- that it should be routine for all stocks to be held 10–14 days prior to distribution and should be free of blown spoilage on dispatch
- careful staff selection and training at all levels

7.11.11 Shelf life

Whilst shelf life is determined by many factors, such as storage temperature and the barrier properties of the particular film used, in general, satisfactory shelf stability in excess of two years is easily obtained for a wide range of products in foil bearing pouches. The US military rations tested over two years at 20°C showed no significant change in product quality ratings. Some products have been successfully stored for as long as seven years and found to be safe and edible.

Foil-free laminates will demonstrate shelf stability commensurate with oxygen permeability of the particular laminate used and the sensitivity of the product. Commercial experience confirms, however, that product stability from four weeks to six months is obtainable. Nitrogen flushing of the outer container has been successful in extending the shelf life of product in foil-free pouches.

Extensive testing under combat conditions by the US Army has proved that retort pouches if correctly packed are well able to stand up to rough conditions including being carried on a soldier's person through tough obstacle courses. Commercial experience in Europe and Japan over many years confirms that pouches can safely withstand distribution through normal trade channels and with a performance equal to that of the rigid metal can.

The retort pouch is probably the most thoroughly tested food packaging system. Its acceptance as the sole form of field rations for the US Army confirms it has fulfilled all that was expected when it was first conceived.

This short review of the integrated activities needed to market the retort pouch indicates the complexity involved and is typical of any major food processing and packaging innovation. Similar principles have been followed in other major food processing and packaging projects, e.g. aseptic packaging, frozen food packaging, etc.

7.12 ENVIRONMENTAL AND WASTE MANAGEMENT ISSUES

7.12.1 Environmental benefit

About 50% of food is packaged in plastics or plastic-based packaging. The main environmental benefit of plastics food packaging is that it saves food from wastage. There are other benefits, such as significant reductions in the weight of packaging waste when plastic packaging is used in preference to alternative forms of packaging, but reducing the waste of resources is the most important environmental benefit. On the subsidiary issues, concerning sustainable development, use of resources and the consequences for manufacture and waste management, the use of plastics for food packaging has a sound environment position.

7.12.2 Sustainable development

The plastics industry overall contributes to achieving the aims of sustainable development. This subject is beyond the scope of this discussion but reference to, for example, the website of PlasticsEurope at www.plasticseurope.org or the British Plastics Federation, www.bpf.co.uk, will indicate the many areas where plastics saves resources, provides possibilities for economic development, social progress and protection of the environment. In Europe, 40% of plastics usage is for packaging, most of which is used in food packaging (*Source*: British Plastics Federation). Plastics in food packaging preserves food, provides choice and convenience.

7.12.3 Resource minimisation – light weighting

Resource minimisation, or lightweighting, refers to the achievement of a similar or better performance with less packaging material. Examples of lightweighting plastic packaging include the following:

- in 1970, the average plastics yoghurt pot weighed 11.8 g. Now only 5.0 g is needed. (*Source*: British Plastics Federation)
- the average weight of plastics film (g/m^2) in 2000 was 36% less than in 1991 (*Source*: PlasticsEurope)
- between 1991 and 2000 the average weight of bottles, containers (kg) reduced by 21% (*Source*: PlasticsEurope)

Further examples are quoted in an INCPEN publication 'Packaging reduction doing more with less'.

The fact that plastics packaging is light in weight reduces the cost of transport of packaging material and packed product, and hence the associated fuel usage and emissions, compared with alternative forms of packaging.

7.12.4 Plastics manufacturing and life cycle assessment (LCA)

In manufacturing, the plastics industry claims that the energy to manufacture compares favourably with, for example, metal ore smelting and glass manufacture and that the processes used are clean. The conversion energy used to make plastic products from pellets is also low in relation to metal and glass processing.

Flexible packaging is energy efficient compared with pre-made packaging, such as glass or metal containers. This is because:

- flexible packaging is transported to the packer either flat or in reel form
- the gross weight of packed product in non-plastic packaging and managing the resulting packaging waste involves, relatively, the use of more energy

These aspects can be evaluated quantitatively by LCA. LCA has been undertaken, using internationally agreed methodology based on ISO Standards. It is conducted in two parts. Firstly, an audit, or eco-profile, is made of all resources in terms of raw materials and energy, entering a previously defined system and the emissions in terms of products, waste heat, emissions to air, water and solid waste leaving the system. The plastics industry has been active in this area and many studies have been completed. The second stage of LCA comprises an assessment of the environmental impact of the process or system. Environmental impact can have local, regional and global implications, and our knowledge and understanding is still developing.

7.12.5 Plastics waste management

7.12.5.1 *Introduction to plastics waste management*

Returnable, refillable and reusable plastic products are in current use. In Sweden, PET drinks bottles are returnable. Plastic pallets, plastic trays and plastic boxes (totes) used in distribution are returnable and reusable. Further development of this concept will reduce the amount of plastic in the waste stream.

Plastic waste arising in manufacture is minimal as thermoplastics can be melted and reused.

The main issue concerns the 40% of the total plastic materials market that is used in packaging, and in particular the proportion that arises in domestic waste or trash. In the United Kingdom, studies have indicated that plastic packaging waste comprises around 8% of household waste by weight (*Source*: Waste & Resources Action Programme, WRAP).

The recovery of domestic plastic waste is a logistical challenge due to there being so many different types of plastic. Additional factors affecting the commercial viability of plastics waste recovery relate to the cost of virgin plastics, the low weight to volume ratio, which increases the handling cost and the fact that the waste arises over a large area geographically. Plastic waste recovery rates in Europe are rising year on year. In 2007, recovery of plastics in the 27 EU Member States plus Norway and Switzerland reached 50% – up 1% on 2006 nine countries (representing 29% of the population) recovered more than 80% of their used plastics, including Switzerland, Denmark, Germany, Sweden, Belgium, Austria, the Netherlands and Norway.

Recovery itself is not recycling. Recovery can either comprise reuse of the material, energy recovery or composting. In 2007, the recycling rate for post-consumer plastics increased to 20.4% – up from 19.5% in 2006. Energy recovery remains unchanged at around 30%. (*Source*: PlasticEurope)

If plastics are to be recycled as material, they must be segregated from other plastics. The most widely recycled items of plastic food packaging are PET bottles and HDPE milk bottles. Both arise in significant volumes and are easily sorted, making the process commercially viable. The plastic is reground for reuse. This process is also referred to as mechanical recycling. Across Europe, 43% of all used PET bottles were collected for recycling in 2007. As traditional markets have become saturated a number of countries are working to ‘close the bottle loop’, i.e. to use reprocessed PET and HDPE for new bottles and food applications.

To assist segregation and sorting, the American Society of the Plastics Industry (SPI) introduced a resin identification code in 1988, which may be displayed on the base of moulded plastic items, see Fig. 7.16. It comprises a numerical code inside a recycling symbol (Mobius strip or loop) together with initial letters relating to the plastic concerned.

Currently, there is no mandatory requirement to identify plastics. However, the British Plastics Federation recommends that large plastic items and packaging should be marked with the appropriate SPI identification code.

7.12.5.2 *Energy recovery*

The thermal content of used plastic is relatively high. An average typical value for polymers found in household waste is 38 MJ/kg, compared with coal at 31 MJ/kg. Incineration with energy recovery produces steam, which can be used to heat buildings and generate electricity. It has the benefit that the plastics do not have to be sorted from other waste. Plastic waste is also

Fig. 7.16 Society of the plastics industry (SPI), resin identification codes.

used as fuel in cement production. Another form of energy recovery for mixed plastic waste is to convert it into fuel pellets, along with other combustible material such as waste paper and board. This material is also known as refuse derived fuel (RDF).

As stated above, of the plastics recovered in Europe (2007), the average proportion incinerated with energy recovery was 30%, but there were large variations in achievement. The UK incinerates with energy recovery only 10% of all municipal waste compared to 78% EfW in Switzerland and 72% in Germany. (*Source*: British Plastics Federation).

There has been concern expressed about possible pollutants arising from the incineration of municipal waste however technology is available to meet the rigorous mandatory internationally agreed safety limits and several countries, Sweden, Germany and Holland, have recently announced plans to expand the existing capacity.

7.12.5.3 *Feedstock recycling*

The feedstock recycling and chemical recycling of petroleum-based plastics is also known as advanced recycling technology. These terms cover a range of processes that convert plastics through the use of heat into smaller molecules that are suitable for use as feedstock for the production of new petrochemicals and plastics. Process names include pyrolysis, glycolysis, hydrolysis and methanolysis. The de-polymerisation of PE and PP is similar to thermal cracking, which is a common oil refinery process. It can only occur in the absence of oxygen.

The subject has created worldwide interest. The techniques are designed to handle contaminated plastic waste materials and are seen as being complimentary to mechanical recycling. According to the American Plastics Council (June 1999), 'feedstock recycling represents a significant technological advancement that in the case of some polymers is already supplementing existing mechanical recycling processes.'

Progress in developing feedstock recycling is slow due to the need for a reliable constant supply of large quantities of used plastic (e.g. 50 000 tonnes per year) and commercial considerations.

A number of processes have been successful. These include Texaco (gasification of plastics waste and conversion to alcohols), BASF (conversion of packaging waste to naphtha cracker feed) and a BP consortium (conversion of household plastics into hydrocarbon feedstock for catalytic or naphtha cracker feed).

In order to invest in commercial units, long-term supply contracts with an appropriate gate-fee are necessary. These logistical and commercial issues have so far prevented full scale development.

7.12.5.4 *Recycled Plastics in Contact with Food*

European Regulation No (EC) 282/2008 sets out the requirements for recycled plastics to be used in food contact materials and establishes an authorisation procedure of recycling processes used in the manufacture of recycled plastics for food contact use. It sets out requirements as regards the materials that can be recycled and the efficiency of the recycling process to reduce contamination. The regulation aims to create a more efficient and practical system for regulating the use of recycled plastics in food packaging.

An important requirement of the regulation is that recycled plastics used in contact with food should only be obtained from processes that have been assessed for safety by the European Food

Safety Agency (EFSA). Guidelines for applicants for the safety evaluation of recycled plastics to be used in contact with food have been published by EFSA.

7.12.5.5 *Bio-based and degradable plastics*

Bio-based and degradable plastics are receiving much interest from the public, media and downstream industries, finding increasing attention as materials of choice for some industrial and consumer applications. The question of their role in food packaging and in plastic usage as a whole is, however, debatable. Some see their use as an answer to the litter problem – but litter is not caused by packaging, it is caused by people. The idea that their use will solve the problem of persistence in landfill goes against the preferred approach for the reuse, recovery and recycling of plastic waste as a more sustainable environmental solution. There are also concerns that the advantages of these materials have been exaggerated and that their presence in the waste stream could potentially prevent conventional recycling. There may, however, be niche markets, such as the packaging of organically grown fruits and vegetables, where their use may be preferred.

Due to concerns relating to fossil resources depletion, increasing demand for renewably resourced products and the consideration of current waste management issues, brand owners and retailers have been increasingly attracted to the attritbutes of both bio-based and degradable plastics.

Plastics derived from natural and renewable sources, such as wood (cellulose), vegetable oils, sugar and starch, can be defined as 'bio-based' plastics. Degradable plastics are those that have the potential to 'break down' in the environment and include those as described in Annex 4.

REFERENCES

AMCOR Lohwasser, W. (2010) AMCOR Flexibles document at http://www.swisslaser.net/libraries.files/LOHWASSER_2010-06-25-Amcor-Swiss-Lasernetwork12.pdf (accessed on 25 June 2010).

Anon (2000a) Plasma (DLC) coating technology from Japan. *PET Planet Insider* 1(6), 18–19.

Anon (2000b) Spendrups is the first into Glaskin high barrier PET. *Brewing Distilling International* 31(4), 48.

Anon (2000c) Beer in PET. *Verpak Berat* 11, 18–19.

Ayshford, H. (1998) Bottle coating suits beer (DLC). *Packaging Magazine* 1(12), 5.

Dai Nippon Printing Co., 2010, information of website. http://www.dnp.co.jp/international/pack/retort/retort_2.html

Frank, M., Ulmer, H., Ruiz, J., Visani, P. and Weimar, U. (2001) Complimentary analytical measurements based on gas chromatography-mass spectrometry, sensor system and human sensory panel: a case study dealing with packaging materials. *Analytica Chimica Acta* 431(1), 11–29 (in English).

Grieg, S., Sherman, P.B., Pitman, R. and Barley, C. (2000) Adhesion promoters: corona, flame and ozone: a technology update, in *Polymers, Laminations and Coatings Conference*. Chicago, IL, USA, 27–31 August 2000, 1.

Haas, D. (1996) Lamination vs coextrusion: a technical and economical analysis, in *LatinPack '96 Conference in Columbia,* 1–2 October, p. 11.

Matsuoka, K., Kakemura, T., Kshima, H., Seki, T. and Tsujino (2002) Development of high barrier plastic bottles, in *Worldpack 2002, Improving the Quality of Life through Packaging Innovation*. East lancing, MI, USA, 23–28 June, 1, pp. 393–399.

Naegeli, H.R. and Lowhesser, W. (2001) Processing and converting of plastic films vacuum coated with inorganic barriers, in *8th European Polymers, Films, Laminations and Extrusion Coatings Conference*. Barcelona, Spain, 28–30 May, p. 18.

Ozguler, A., Morris, S.A. and O'Brien, W.D. (1999) Ultrasonic seal tester (retort pouches). *Packaging Technology and Science* 12(4), 161–171.

Potente, H., Heil, M. and Korte, J. (1995) Laser lamination of thermoplastics. *Plastverarbeiter (in German)* 46(9), 42–44, 46.

FURTHER READING

Soroka, W. (2002) *Fundamentals of Packaging Technology*, revised UK edn, Emblem, A. and Emblem, H. (eds.). The Institute of Packaging, Naperville, Illinois, USA, ISBN 0 9464 6700 5.

Packaging Reduction – Doing More with Less. INCPEN, London, United Kingdom. Available from: http://www.incpen.org.

WEBSITES

- British Plastics Federation www.bpf.co.uk.
- Plastics Europe www.plasticseurope.org.
- American Plastics Council www.americanplasticscouncil.org.
- Biodegradable Plastics Society www.bpsweb.net/02_english.
- European Bioplastics http://www.european-bioplastics.org/.
- Ceramis Coating Technology at www.amcor.co./businesses/food/Ceramis.html.
- Natureworks www.natureworksllc.com.
- Biomax resins www.dupont.com/polyester/resins/products/biomax.html.
- Website for European Plastics in Contact with Food regulations, see http://ec.europa.eu/food/food/chemicalsafety/foodcontact/legisl_list_en.htm#02–72.
- European Food Safety Agency www.efsa.europa.eu.
- Plastics New Zealand www.packagingaccord.org.nz.

For general information on plastics, search websites of major plastic resin manufacturers.

APPENDICES

Appendix 1 Simple physical tests for polyolefin film identification.

Action	Observation	Conclusion
Pull in both directions	Stretches easily in both directions	Cast PE or PP
	Stretches easily in MD and splits, but not in TD	Mono axial PE
	Glass clear, becoming white in stressed areas	Cast PP
	Cloudy to milky white in stressed areas	MDPE or HDPE
	Stretches more easily in MD than TD	Orientated by Stenter
	Stretches easily in both directions	Biaxial HDPE
	Difficult to stretch in both directions	Bubble blown OPP
	Extreme force required to stretch	PET or PA
If white or pearlescent	With cavitation	Stentered OPP
	Solid uniform film	Bubble blown OPP
Surface scratches	Coated film	OPP most likely

Appendix 2 Resistance to heat.

Film	Manner of Burning	Colour of flame	Odour after extinguishing
OPP	Melts, shrivels drips	Blue	Acrid
PE	Melts easily, drips	Blue	Burning Candle
PET	Softens, burns steadily	Yellow	Pleasant
PVC	Will not burn	Yellow with Green	Acrid, choking
PS	Burns easily in drips	Yellow	Acrid

Appendix 3 Identification of coating.

Coating	Methanol (apply 1 drop)	Blue methanol colour change	Copper wire + flame	Surface appearance
Acrylic	White after drying	Dark blue	No colour	Glossy
PVdC	No colour after drying	None	Green flame	Very slightly yellow
LTSC (low temp. sealing coating)	None	Dark blue	None	Glossy
PVOH	None	None	None	Glossy

Appendix 4 Bio-based and degradable plastics.

Types of degradable plastics and examples:

	Description	Examples
Biodegradable	Plastics derived from either renewable or fossil materials. *One step*: biodegradation – as a result of the action of micro-organisms the material is ultimately converted to water, carbon dioxide, biomass and possibly methane.	Mater-bi® (Novamont) Ingeo™ (Natureworks LLC) Ecoflex® (BASF)
Compostable	Can be either bio-based or petroleum-based. Plastic will fragment and ultimately biodegrade in a composting process and converted to carbon dioxide, water and biomass with no toxic side effects; Conforms to international composting standards such as, EN 13432 or ASTM 6400.	Ecoflex (BASF) Mater-bi® (Novamont)
Hydro-degradable	*Two step*: degredation begins by a chemical process (hydrolysis) followed by biodegradation. Single step 'water soluble' plastics do exist.	Biomax® (DuPont)
Oxo-degradable	Primarily fossil-based plastics modified with additives for 'controlled life'. *Two step*: degredation begins by a chemical process (oxidation) followed by biodegradation.	TDPA™ (totally degradable plastic additive): EPI Global d2w®: Symphony Environmental