CHAPTER 5: PLASTICS PACKAGING

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5.1 Learning Objectives

This module has been written to provide a basic understanding of, and introduction to, plastics packaging. On completion of this module, the student will have a general appreciation of the structure and properties of the major plastics used in food packaging. In addition, the barrier properties of plastic polymers in terms of their transmission rates will also be covered.

5.2 Introduction

The adjective *plastic* is derived from the Greek *plastikos* meaning easily shaped or deformed; it was first introduced into the English language in the 19th century to describe the behavior of the recently discovered cellulose nitrate which behaved like clay when mixed with solvents.

*Plastics* can be defined as an arbitrary group of materials based on synthetic or modified natural polymers which at some stage of manufacture can be formed to shape by flow, aided in many cases by heat and pressure.

Flexible materials depend for their usefulness on the properties of long, flexible molecules interlocked into a strong and non-brittle lattice. These structures are built up by the repeated joining of small basic building blocks called *monomers*, the resulting compound being called a *polymer*. Differences in the chemical constitution of the monomers, in the structure of the polymer chains, and in the interrelationship of the chains, determine the different properties of the various polymeric materials.

Plastic polymers can be divided into two broad categories: those polymers which extend in one dimension (i.e. they consist of linear chains), and those polymers which have links between the chains, so that the material is really one giant molecule.

The first group is the *linear polymers* and they are *thermoplastic*, i.e. they gradually soften with increasing temperature and finally melt because the molecular chains can move independently. They are characterized by extremely long molecules with saturated carbon-carbon backbones. Such polymers may be readily molded or extruded because of the absence of cross-links. If their temperature is raised, they become very flexible and can be molded into shape even at temperatures below their melting point. Not surprisingly, their mechanical properties are rather temperature sensitive. Thermoplastics are the most important class of plastics material available commercially, and account for more than two-thirds of all polymers used in the world today.

The second group is the *cross-linked polymers* and they are *thermosetting*. As the name suggests, these polymers become set into a given network when manufactured and cannot be subsequently remolded to a new shape. At normal temperatures the cross-links make the solid quite rigid. Thermosetting polymers do not melt on heating but finally blister (due to the release of gases) and char. Examples of thermosetting plastics are epoxy resins. The importance of thermosetting polymers in food packaging is minimal except for epoxy resins which find use as enamels.
(lacquers) for metal cans.

The table below shows how, by increasing the length of the carbon chain (the number of carbon atoms joined together), the properties of a hydrocarbon material (i.e., one consisting only of carbon and hydrogen atoms) change from a gas to a liquid and eventually to a solid. It is only when the number of carbons in the chain exceeds 1000 that a true polymer is formed.

<table>
<thead>
<tr>
<th>Number (n) of Carbons in Chain</th>
<th>State and Properties of Material</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>Simple gas</td>
<td>Gas</td>
</tr>
<tr>
<td>5-11</td>
<td>Simple liquid</td>
<td>Gasoline</td>
</tr>
<tr>
<td>9-16</td>
<td>Medium viscosity liquid</td>
<td>Kerosene</td>
</tr>
<tr>
<td>16-25</td>
<td>High viscosity liquid</td>
<td>Oil &amp; grease</td>
</tr>
<tr>
<td>25-50</td>
<td>Crystalline solid</td>
<td>Paraffin wax</td>
</tr>
<tr>
<td>50-1000</td>
<td>Semicrystalline solid</td>
<td>Milk carton, adhesives, coatings</td>
</tr>
<tr>
<td>1000-5000</td>
<td>Tough plastic solid</td>
<td>Poly(ethylene) bottles</td>
</tr>
<tr>
<td>$3 \times 10^5$</td>
<td>Fibers</td>
<td>Fabrics</td>
</tr>
</tbody>
</table>

5.3 Transmission Rates

In contrast to packaging materials made from glass or metal, packages made from thermoplastic polymers are permeable to varying degrees to small molecules such as gases, water vapor, organic vapors and other low molecular weight compounds. Therefore in selecting a plastic polymer it is useful (indeed essential) to know how much protection will be provided by the plastic to water vapor, gases, etc. The term *transmission rate* is used to indicate how good a barrier a particular plastic polymer is.

The Transmission Rate (TR) of a plastic polymer is defined as:

$$ TR = \frac{Q}{A \cdot t} $$

Where:

- $Q$ is the amount of permeant passing through the polymer;
- $A$ is the area, and
- $t$ is the time.

Permeabilities of polymers to water and organic compounds are often presented in this way, and in the case of water and oxygen, the terms WVTR (Water Vapor Transmission Rate) and OTR (Oxygen Transmission Rate) are in common usage.

When quoting a TR it is necessary to know either the pressure or the concentration of permeant, and the thickness of the polymer, under the conditions of measurement. Without this information the TR is meaningless.

Since the TR is not a real constant which is characteristic for a polymer, it should only be used as a means of comparing orders of magnitude. The typical units for TR are (g m$^{-2}$ day$^{-1}$) for water vapor and (mL m$^{-2}$ day$^{-1}$) for gases.

Data on WVTR’s are commonly reported for 38°C and relative humidities on the high pressure side of 95% and on the low pressure side of
0% (so-called tropical conditions). Data on OTR’s are commonly reported for 23°C and relative humidities of zero on both the high pressure and low pressure sides. Sometimes a pressure term is included when OTRs are quoted (e.g., mL m⁻² day⁻¹ atm⁻¹). This is because the measurements are made with 100% O₂ on one side of the polymer and zero on the other. However, in real life it is likely that there will be air on one side rather than 100% O₂. In these situations it is necessary to multiply the OTR by 0.21 to get the actual OTR (this is because the concentration of O₂ in air is 21%) with units of mL m⁻² day⁻¹.

Typical TRs for a variety of polymers are given below:

<table>
<thead>
<tr>
<th>Film</th>
<th>WVTR</th>
<th>OTR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g m⁻² day⁻¹</td>
<td>mL m⁻² day⁻¹</td>
</tr>
<tr>
<td>LDPE</td>
<td>15-20</td>
<td>1300-1800</td>
</tr>
<tr>
<td>HDPE</td>
<td>7-10</td>
<td>330-420</td>
</tr>
<tr>
<td>LLDPE</td>
<td>15-20</td>
<td>1300-1800</td>
</tr>
<tr>
<td>PP cast</td>
<td>10-12</td>
<td>730-950</td>
</tr>
<tr>
<td>OPP</td>
<td>5-7</td>
<td>420-530</td>
</tr>
<tr>
<td>PET</td>
<td>15-20</td>
<td>21-32</td>
</tr>
<tr>
<td>mPET</td>
<td>1-2</td>
<td>21-32</td>
</tr>
<tr>
<td>PVC</td>
<td>30-40</td>
<td>30-75</td>
</tr>
<tr>
<td>PA</td>
<td>300-400</td>
<td>10-16</td>
</tr>
<tr>
<td>PS</td>
<td>70-150</td>
<td>300-1300</td>
</tr>
</tbody>
</table>

Transmit rates for polymers 25µm thick; mPET is metalized PET

What this means in practice is that if you took a 1 square meter sheet of say low density polyethylene film 25 microns thick and held it at 38°C with relative humidities on the high pressure side of 95% and on the low pressure side of 0%, 15-20 grams of water vapor would pass through the film in 24 hours. One of the reasons that a range of values is given for a particular polymer is that there is considerable variation between manufacturers as a result of slightly different process conditions including temperature, pressure and catalysts.

OTR and WVTR of selected polymers

When selecting a suitable plastic polymer to package a product it is necessary to know just how much protection the food needs from water vapor, oxygen or carbon dioxide. For moist products (e.g. fresh fruits and vegetables) loss of water vapor should be avoided, while for dry products (e.g. crackers) gain of moisture should be avoided. For carbonated beverages loss of carbon dioxide needs to be avoided. It is possible to make calculations of the shelf life of a food when packaged in different plastic polymers, thus ensuring that the most cost-effective polymer is chosen. However, such calculations are outside the scope of this module.
5.4 Polyethylene

This is the largest volume single polymer used in food packaging in both the film and blow-molded form. It is a polymer of ethylene (C₂H₄), a hydrocarbon gas available in large quantities as a by-product of petroleum refining and other processes.

\[
\text{ethylene} \rightarrow \text{polymerization} \rightarrow \text{polyethylene}
\]

Three dimensional model of polyethylene

5.4.1 Low Density Polyethylene (LDPE)

LDPE (low density polyethylene) is a tough, slightly translucent material which has good tensile strength, burst strength, impact resistance and tear strength, retaining its strength down to -60°C. While it is an excellent barrier to water and water vapor, it is not a good barrier to gases.

It has excellent chemical resistance, particularly to acids, alkalis and inorganic solutions, but is sensitive to hydrocarbons and halogenated hydrocarbons, and to essential and vegetable oils. One of the great attributes of LDPE is its ability to be fusion welded (i.e., heat sealed) to itself to give good, tough, liquid-tight seals.

As well as its use as a film, LDPE also finds wide use as a rigid packaging material. It can be easily blow molded into bottles where its flexibility enables the contents to be squeezed out. It is also widely used in the form of snap-on caps, collapsible tubes and a variety of spouts and other dispensers.

There are many hundreds of grades of LDPE available, most of which differ to varying degrees in their properties. Polyethylene is one of the most inert polymers and constitutes no hazard in normal handling.

5.4.2 High Density Polyethylene (HDPE)

HDPE possesses a much more linear structure than LDPE. Although some branch chains are formed, these are short and few in number. HDPE film is stiffer and harder than LDPE and densities range from 941-965 kg m⁻³. Its softening point is about 121°C, and its low temperature resistance about the same as LDPE. Tensile and bursting strengths are higher but impact and tear strengths are both lower than LDPE. Of interest is the fact that due to the linear nature of the HDPE
molecules, they tend to align themselves in the direction of flow and thus the tear strength of the film is much lower in the machine direction compared to the transverse direction.

The chemical resistance of HDPE is also superior to that of LDPE and, in particular, it has better resistance to oils and greases. The film offers excellent moisture protection, a much decreased gas permeability compared with LDPE film, but is much more opaque. Heat sealing is considerably more difficult compared to LDPE film.

HDPE film has a white, translucent appearance and therefore tends to compete more with paper than transparent films. To be competitive with paper on a price-per-unit-area basis, it must be thin, and consequently much of the HDPE film used is only 10-12 µm thick.

HDPE is blow molded into bottles for a variety of food packaging applications, although its uses in this area have tended to be taken up by PET bottles which generally have better barrier properties than HDPE.

5.4.3 Linear Low Density Polyethylene (LLDPE)

Linear LDPE (LLDPE) has a similar molecular structure to HDPE but is virtually free of long chain branches but does contain numerous short side chains. These arise as a result of copolymerizing ethylene with a smaller amount of propene, butane, hexane or octene. Such branching interferes with the ability of the polymer to crystallize, and therefore results in LLDPE having a similar density to LDPE. The linearity provides strength, while the branching provides toughness. It was not until 1977 that LLDPE became available in commercial quantities.

The term linear in LLDPE is used to imply the absence of long chain branches. Due to the linearity of its molecules, LLDPE is stiffer but less transparent than LDPE, resulting in an increase of 10-15°C in the melting point of LLDPE compared to LDPE. LLDPE has higher tensile strength, puncture resistance, tear properties and elongation than LDPE.

LLDPE combines the main features of both LDPE and HDPE, a major feature being that its molecular weight distribution is narrower than that of LDPE. Generally, the advantages of LLDPE over LDPE are improved chemical resistance, improved performance at both low and high temperatures, higher surface gloss, higher strength at a given density, better heat sealing properties and a greater resistance to environmental stress cracking. In film form, LLDPE shows improved puncture resistance and tear strength. At a density of 920 kg m⁻³ the melting points of LDPE and LLDPE are 95°C and 118°C respectively. LLDPE commonly has a density around 920 kg m⁻³ when butene is used as the comonomer. The superior properties of LLDPE have led to its use in new applications for polyethylene as well as the replacement of LDPE and HDPE in some areas; LLDPE is also often blended with LDPE.

5.5 Polypropylene (PP)

PP is a linear polymer. Depending on the type of catalyst and
polymerization conditions, the molecular structure of the resulting polymer consists of the three different types of stereo configurations: *isotactic*, *syndiotactic* and *atactic*. Industrial processes are designed to minimize the production of *atactic* PP where the methyl groups are randomly distributed on either side of the chain.

![Polyethylene](image)

*Isotactic polypropylene (all CH$_3$ methyl groups are below the horizontal plane)*

The most regular crystalline polymer is known as the *isotactic* form, the name stemming from the original idea that the methyl groups were always above or below the horizontal plane. Isotactic PP is a highly crystalline material with good chemical and heat resistance but poor transparency. Another form is *syndiotactic* where the methyl groups alternate above and below the horizontal plane. Isotactic PP is stiff, highly crystalline and has a high melting point. PP has a lower density (900 kg m$^{-3}$) and a higher softening point (140°- 150°C) than the polyethylenes, low WVTR, medium gas permeability, good resistance to greases and chemicals, good abrasion resistance and high temperature stability, as well as good gloss and high clarity, the latter two factors making it ideal for reverse printing (i.e., printing on the underside of the film so that the natural gloss of the film will enhance the appearance).

PP can be blow molded and injection molded, the latter process being widely used to produce closures for HDPE, PET and glass bottles, as well as thin-walled pots and crates. Copolymerization with 4-15% of ethylene improves the strength and lowers the melting point. Such copolymers are often preferred to the homopolymer in injection molding and bottle blowing applications, and also find use in shrink wrapping where the lower melting point is an advantage.

Non-oriented PP film is often referred to as cast PP film because it is generally made by the chill-roll cast process, although other methods can be used. PP film is a very versatile material, being used as a thermoformable sheet, in cast form for film and bags, and as thin, strong biaxially-oriented films for many applications. Cast and oriented PP are sufficiently different that they do not compete for the same end uses, the cost of cast PP being much lower than that of oriented PP. The cast form has polyethylene-type uses while the oriented form has regenerated cellulose film (RCF)-type uses and has largely replaced RCF in food packaging applications. Cast PP use in food packaging is limited owing to its brittleness at below-freezing temperatures, and it is generally not recommended for use with heavy, sharp or dense products unless laminated to stronger, more puncture-resistant materials.
**Orientation**

The process of stretching a plastic film to improve its physical properties by aligning the molecular chains. Stretching in one direction is referred to as uniaxial orientation. Stretching in two directions is referred to as biaxial orientation (BO).

The relatively high temperature resistance of PP permits its use as the seal layer in retortable pouches, hot-filled bottles and microwaveable packaging. In recent years there has been a large increase in the use of oriented polypropylene (OPP) for food packaging. Wide variations are possible in the extent of orientation in two directions (biaxial orientation or BOPP), leading to a wide range of properties. BOPP film has a tensile strength in each direction roughly equal to four times that of cast PP film. Biaxial orientation also improves the moisture barrier properties of PP film and its low temperature impact strength. OPP film is not considered to be a gas barrier film but this deficiency can be overcome by coating with PVC-PVdC copolymer. OPP films often have a stiff feel and tend to crinkle audibly.

If heating sealing is required, PP is normally coated with a lower melting point polymer because shrinkage tends to occur when highly stretched film is heated.

A relatively new addition to the family of OPP films is white opaque film known as pearlized film since the diffusion of light gives the film the visual effect of pearlescence. Homopolymer resin is evenly mixed with a small amount of foreign particulate matter such as starch.

White opaque OPP films find application in snack food packaging, candy-bar overwraps, beverage bottle labels, soup wrappers and other applications that have traditionally used specialty paper-based packaging materials.

5.6 Polystyrene

If ethylene and benzene are reacted together with a suitable catalyst, ethylbenzene is formed and by a process of catalytic dehydrogenation, styrene (commonly known as vinyl benzene) is produced. Polystyrene (PS) is made by the addition polymerization of styrene. The polymer is normally atactic and is thus completely amorphous because the bulky nature of the benzene rings prevents a close approach of the chains. With the use of special catalysts and polymerization techniques, isotactic PS has been prepared but it reverts to the atactic form on melting.

\[
\begin{align*}
\text{PS} & = \text{CH}_2 - \text{CH} - \\text{C} \\
\end{align*}
\]

PS was the first of the moldable clear rigid plastics to reach the commercial market in large volumes in the late 1940s. It could be rapidly molded into finished shapes because of its ease of flow in the melt and its fast-setting nature from the melt.

5.6.1 General Purpose Polystyrene (GPPS)

In this form it is commonly referred to as crystal grade PS and is the unmodified homopolymer of styrene. It is stiff and brittle at room temperature with no melting temperature but excellent optical properties.
PS makes a distinctly metallic sound when dropped onto a hard surface. It has a high refractive index (1.592) which gives it a particularly high brilliance. Although acids and alkalis have no effect on it, it is soluble in higher alcohols, ketones, esters, aromatic and chlorinated hydrocarbons, and some oils. Even if it is not soluble in the material, cracking and even chemical decomposition of PS may occur. The extent of the decomposition depends on the grade of PS, the time and temperature of exposure, and the concentration of the reagent. While a reasonably good barrier to gases, it is a poor barrier to water vapor.

Crystal grade PS can be made into film but it is brittle unless the film is biaxially oriented. The oriented film can be thermoformed into a variety of shapes although special techniques have to be used because orientation gives it a tendency to shrink on heating.

New applications of PS involve coextrusion with barrier resins such as EVOH and PVC-PVdC copolymers to produce thermoformed, wide-mouthed containers for shelf stable food products and multilayer blow molded bottles.

5.6.2 High Impact Polystyrene (HIPS)

To overcome the brittleness of PS, synthetic rubbers can be added during polymerization at levels generally not exceeding 25% w/w for rigid plastics. The rubbers act by restricting propagation of microcracks formed during impact loading. Although copolymerization increases impact strength and flexibility, the transparency, tensile strength and thermal resistance is much reduced. The chemical properties of this toughened or high impact polystyrene (HIPS) are much the same as those for unmodified polystyrene.

HIPS is an excellent material for thermoforming. Because it is transparent, the use of radiant heat for thermoforming is inefficient and pigmented sheet is often used. It is injection molded into tubs which find wide use in food packaging, despite their being opaque. Transparent unit packs are made from untoughened PS.

5.6.3 Expandable Polystyrene Sheet (EPS)

The properties of PS that make it useful for many applications as a solid polymer also make it very desirable as a foam. PS foam has a high modulus, good water resistance, low moisture transmission, ease of fabrication and low cost. Closed cell foams have excellent thermal insulating capability, low weight and good cushioning characteristics. The combination of those properties provides a wide spectrum of products.
Most PS foam sheet is used for disposable packages such as meat and produce trays, egg cartons, disposable dinnerware and containers for take-away or carry-out meals.

5.7 Polyethylene Terephthalate (PET)

PET can be produced by reacting ethylene glycol (EG) with terephthalic acid (TPA), although in practice the dimethyl ester of TPA (dimethyl terephthalate or DMT) is used to give a more controllable reaction. EG is obtained from ethylene; TPA is prepared by the partial oxidation of p-xylene, itself a by-product of the petroleum industry.

PET is a linear, transparent thermoplastic polymer. It has the capacity to crystallize under certain controlled conditions. PET is strong, stiff, ductile and tough and can be oriented by stretching during molding and extrusion, which increases its strength and stiffness still further. PET bottles and films are largely amorphous with excellent transparency. PET films are most widely used in the biaxially oriented, heat stabilized form. Subsequent coatings are applied to obtain special barrier properties, slip characteristics or heat sealability.

PET film’s outstanding properties as a food packaging material are its great tensile strength, excellent chemical resistance, light weight, elasticity and stability over a wide range of temperatures (-60° to 220°C). This latter property has led to the use of PET for ‘boil-in-the-bag’ products which are frozen before use (the PET is usually laminated to or extrusion coated with LDPE and is typically the outside and primary support film of such laminations), and as oven bags where they are able to withstand high temperatures without decomposing.

Although many films can be metalized by applying a very thin coating aluminum particles, PET is the most common. Metallization results in a considerable improvement in barrier properties. Reductions in WVTRs by a factor of 40 and O$_2$ permeabilities by
over 300 are obtained. Coextruded heat sealable films are frequently metalized and used as the inner ply of snack food packages. Rigid grades of metalized PET can be used in thermoformable applications.

PET bottles with preforms in the front

The bottles are stretch blow molded, the stretching or biaxial orientation being necessary to get maximum tensile strength and gas barrier, which in turn enables bottle weights to be low enough to be economical.

PET is also used to make ‘ovenable’ trays for frozen food and prepared meals, where they are preferable to foil trays because of their ability to be microwaved without the necessity for an outer paperboard carton.

In the 1970s the benefits of biaxial orientation of PET were extended from sheet film to bottle manufacture. The first commercial production appeared on the market in 1977. As a result, important new markets developed, particularly for carbonated beverages.

5.8 Polyvinyl Chloride

Ethylene dichloride is formed by an addition reaction of chlorine with ethylene, and the dichloride is then ‘cracked’ to give vinyl chloride monomer (VCM). Addition polymerization of VCM produces poly(vinyl chloride) (PVC).
Vinyl polymers and copolymers make up one of the most important and diversified groups of linear polymers. This is because PVC can be compounded to produce a wide spectrum of physical properties. This is reflected in the variety of uses to which it is put, from exterior guttering and water pipes to very thin, flexible surgeons' gloves. It is the second most widely used synthetic polymer after polyethylene and is commonly referred to simply as ‘vinyl’.

A range of PVC films with widely varying properties can be obtained from the basic polymer. The two main variables are changes in formulation (principally plasticizer content) and orientation. The former can give films ranging from rigid, crisp films to limp, tacky and stretchable films. The degree of orientation can also be varied from completely uniaxial to balanced biaxial.

Extremely clear and glossy films can be produced having a high tensile strength and stiffness. The density is high at around 1400 kg m$^{-3}$. The water vapor permeability is higher than that of the polyolefins but the gas permeability is lower. Unplasticized PVC has excellent resistance to oils, fats and greases and is also resistant to acids and alkalis.

To a large extent the properties of plasticized PVC depend on the type of plasticizer used, as well as the quantity. For these reasons it is difficult to be very specific about the physical properties of PVC due to the wide range of plasticization possible. The amount of plasticizer can vary up to 50% of the total weight of the final material. Because plasticizers are not bound chemically, they tend to migrate to the surface where they are lost by abrasion, solution or slow evaporation, leaving a more brittle, stiffer material behind.

Films with excellent gloss and transparency can be obtained provided that the correct stabilizer and plasticizer are used. Both plasticized and unplasticized films can be sealed by high frequency welding techniques. PVC is inert in its chemical behavior, being self-extinguishing when exposed to a flame.

Thin, plasticized PVC film is widely used for the stretch wrapping of trays containing fresh red meat and produce. The relatively high WVTR of PVC prevents condensation on the inside of the film. Oriented films are used for shrink wrapping of produce and fresh meat, but in recent years LLDPE films have increasingly replaced them in many applications.

Unplasticized PVC as a rigid sheet material is thermoformed to produce a wide range of inserts from chocolate boxes to biscuit trays, but in recent years they have been increasingly replaced by PET.
5.9 Polyvinylidene Chloride (PVdC)

PVdC homopolymer is made from vinylidene chloride monomer which has two chlorine atoms attached to every second carbon atom (vinyl chloride monomer has one chlorine atom attached to every second carbon atom).

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  n  CH₂-C(Cl)
      \  \n      C  C
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It has a melting temperature only a few degrees below the temperature at which it decomposes and yields a rather stiff film which is unsuitable for packaging purposes. Therefore copolymers were synthesized in an effort to overcome these properties.

When PVdC is copolymerized with 5 to 50% (but typically 20%) of vinyl chloride, a soft, tough and relatively impermeable film results. These copolymers were first marketed by Dow in 1940 under the trade name Saran® and are usually referred to simply as PVdC copolymer. The specific properties of PVdC copolymer vary according to the degree of polymerization and the properties and relative proportions of the copolymers present.

The properties of PVdC copolymer film include a unique combination of low permeability to water vapor, gases and odors, as well as greases and alcohols. It also has the ability to withstand hot filling and retorting, making it a useful component in multilayer barrier containers. Although highly transparent, it has a yellowish tinge. It is an important component of many laminates. PVdC copolymers can be sealed to themselves and to other materials.

By itself the copolymer is frequently used as a shrink film since orientation improves tensile strength, flexibility, clarity, transparency and impact strength. As well, gas and moisture permeabilities are lowered and tear initiation becomes difficult.

5.10 Polyamides (nylons)

PAs are condensation, generally linear thermoplastics made from monomers with amine and carboxylic acid functional groups that provide mechanical strength and barrier properties. Their development was not fortuitous but the result of a long search for a family of polymers that would resemble silk, the most highly valued of all natural textile fibers. The first synthesized was nylon 6,6 in 1935 with commercial production commencing in 1939. However, PAs did not become a commercial reality for packaging film applications until the late 1950s. Although considered a specialty film, many presently available food packages would not be possible without PAs.

Although over 100 different formulations are available in the production of PA film, most of those used in food packaging applications consist of nylons 6,6, 6 and 11.
Although each variety of PA film has its own characteristic properties, certain similarities exist. PA films are characterized by excellent thermal stability, i.e. they are capable of withstanding steam at temperatures up to 140°C and dry heat to even higher temperatures. Low temperature flexibility is excellent and they are resistant to alkalis and dilute acids.

In general PAs are highly permeable to water vapor, the absorbed water having a plasticizing effect which causes a reduction in tensile strength and an increase in impact strength. Their permeability to O₂ and other gases is quite low when the films are dry. Odor retention is excellent and the films are tasteless, odorless and nontoxic. Other important attributes of PAs are their excellent thermoformability, flex-crack resistance, abrasion resistance and mechanical strength up to 200°C.

For most applications PAs are combined with other materials such as LDPE, ionomer and EVA to add a moisture barrier and heat sealability. Multilayer films containing a PA layer are used principally in the vacuum packing of processed meats and cheeses.

Biaxial orientation of PA films provides improved flex-crack resistance, mechanical strength and barrier properties. These films have applications in packaging foods such as processed and natural cheese, fresh and processed meats, and frozen foods. They are used in pouches and bag-in-box structures. In some applications the PAs compete with biaxially oriented PET; although oriented PAs offer better gas barrier, softness and puncture resistance, oriented PET offers better rigidity and moisture barrier.

In the 1980s a new polymer, MXD6, was introduced. MXD6 has better gas barrier properties than nylon 6 and PET at all humidities, and is better than EVOH at 100% RH. For example, nylon 6 is five times as permeable as MXD6 at 0% RH and twelve times as permeable at 75% RH. Biaxially oriented film produced from MXD6 is used in several packaging applications as it has significantly higher gas and moisture barrier properties, and greater strength and stiffness, than other PAs.

Together with its high clarity and good processability, the above properties make MXD6 film suitable as a base substrate for laminated film structures for use in lidding and pouches, especially when the film is exposed to retort conditions. Coextruded PET-MXD6-PET has been used as a container for beer and wine.

Laminate with MXD6 in a retortable package
Three-layer preforms have an MXD6 nylon barrier to meet the 20-week shelf-life requirement for carbonated soft drinks.

5.11 Ethylene Vinyl Acetate (EVA)

Ethylene vinyl acetate (EVA) is a random copolymer whose properties depend on the VA content and molecular weight. EVA with a VA content of 3-12% is similar in flexibility to plasticized PVC, and has good low temperature flexibility and toughness.

EVA copolymers are not competitive with normal film because of their high surface tack and friction which make them difficult to handle on conventional processing machinery. However, they do have three advantages over LDPE: the heat sealing temperature is lower, the barrier properties are better, and they have excellent stretch properties, the first 50% of extension at room temperature being elastic. Thus they find use as a stretch film for food packaging (particularly fresh meat) and cling-wrap purposes, and have replaced PVC for many stretch wrapping applications. Some EVA is used in coextrusion processes for the manufacture of laminated material. As a heat sealing layer, EVA is used in the extrusion coating of PET and BOPP films.

5.12 Ethylene Vinyl Alcohol (EVOH)

EVOH copolymers were commercialized in Japan by the Kuraray company in 1972 and in the US and Europe in the early 1980s. EVOH copolymer is produced by a controlled hydrolysis of EVA copolymer, the hydrolytic process transforming the VA group into VOH; there is no VOH involved in the copolymerization. The vinyl alcohol base has exceptionally high gas barrier properties, but is water soluble and difficult to process.

EVOH copolymers offer not only excellent processability, but also superior barriers to gases, odors, fragrances, solvents, etc. It is these characteristics that have allowed plastic containers containing EVOH barrier layers to replace many glass and metal containers for packaging food.

The most outstanding characteristic of EVOH is its ability to provide a barrier to gases and odors. Its use in a packaging structure enhances flavor...
and quality retention by preventing O₂ from penetrating the package. EVOH also provides a very high resistance to oils and organic vapors. However, as moisture is absorbed, the gas barrier properties are affected. Through the use of multilayer technology to encapsulate the EVOH layer with high moisture barrier resins such as polyolefins, the moisture content of the barrier layer can be controlled and its oxygen barrier properties retained.

### Effect of humidity on OTR of three films

Rigid and semi-rigid containers such as bottles, trays, bowls and tubes, flexible films and paperboard beverage cartons containing EVOH as the functional barrier layer are commercially available. Most multilayer structures have five or six layers, with seven- and nine-layer structures being produced for special applications, the EVOH always being surrounded by polymers such as polyolefins which provide a good barrier to water vapor. When using EVOH in multilayer structures, it is necessary to use an adhesive or tie layer to gain adequate bonding strength to the other polymers.

![Diagram of Rigid package containing EVOH for olive oil](image)

#### 5.13 Regenerated Cellulose Film (RCF)

Cellophane is now a generic term for regenerated cellulose film (RCF) except in certain countries where ‘cellophane’ is a registered trade name.

Regenerated cellulose is manufactured from highly purified cellulose usually derived from bleached sulfite wood pulp. The pulp, in sheet or roll form, is steamed in sodium hydroxide to form soda cellulose and then shredded. The alkali cellulose is then aged to begin the molecular depolymerization process, after which carbon disulfide is added. Viscose is formed by adding dilute sodium hydroxide, causing the cellulose to dissolve into solution. The viscose is then extruded through a slot-die into acid-salt coagulating and regenerating tanks to give a regenerated cellulose film (RCF). The film is then run through a bath containing glycerol or ethylene glycol which act as plasticizers and confer flexibility on the film. Finally it is passed through a drying oven and wound up as plain, non-moisture-proof film.
RCF can be regarded as transparent paper. However, it is not a plastic since it will not melt and cannot be formed by heat and pressure. If uncoated it is highly permeable to steam, and when immersed in water can absorb its own weight of water. Although impervious to gases when dry, in a wet state it is pervious to varying degrees. It is impervious to fats and oils and insoluble in organic solvents. It does not have the same tensile strength as plastic films, and is non-resistant to strong acids and alkalis. As it is flammable it cannot be heat sealed. It is not surprising therefore that in its plain uncoated form it has very few uses.

For food packaging applications it is always used after various coatings have been applied to one or both sides. The type of coating largely determines the protective properties of the film. There are four types of coatings which can be applied to regenerated cellulose to confer on it properties which make it a desirable film for food packaging applications. They are:

- **Nitrocellulose** - these lacquers contain nitrocellulose, resins, plasticizers, waxes and agents to prevent surface blocking. This is the commonest type of coating and provides a moisture barrier.
- **PVC** - this is designed to provide excellent machinability and offers properties and cost intermediate to that of the nitrocellulose-coated and copolymer-coated cellophane.
- **PVC/PVdC** - this gives superior product protection, preventing volatile aromatic flavors getting out and O₂ from getting in to oxidize those flavors. It is commonly referred to as copolymer-coated cellophane.
- **LDPE** - this coating is used for premium packaging where no moisture loss but high O₂ permeability and heat sealability is required.

In recent years RCF has been replaced in many food packaging applications by plastic films (especially BOPP). However, its unique properties ensure that it is still used for the twist wrapping of sweets.

5.14 **Biobased Plastics**

With the exception of paper-based products, food packaging materials have traditionally been based on non-renewable materials. This was not always so, and up until the beginning of the 20th century, packaging
materials, together with other industrial products such as inks, dyes, paints, medicines, chemicals, clothing and plastics were made from biologically-derived resources. During the 20th century, petroleum-derived chemicals replaced biologically-derived resources for most of these industrial products. Now at the beginning of the 21st century, increasing attention is being given to sustainability and the replacement of non-renewable resources (particularly those derived from petroleum) with those from renewable sources, essentially plant-derived products and by-products from their fermentation.

However, from a public point of view, the main drivers for the development of biodegradable packaging are the solid waste problem (particularly the perception of a lack of landfills), the litter problem which the public feel would be solved if biodegradable packaging were used, and pollution of the marine environment by nonbiodegradable packaging. The synthetic polymers used today take 200 years to degrade if exposed to the atmosphere, and longer if placed in a landfill. Of course glass and metal packaging never degrades although metal packaging may oxidize and lose its mechanical integrity.

A biodegradable plastic is one in which the degradation process results in lower molecular weight fragments produced by the action of naturally-occurring microorganisms such as bacteria, fungi and algae.

The challenge for the successful use of biodegradable polymer products in food packaging is achieving the desired shelf life followed by efficient biodegradation after disposal. Obviously premature biodegradation and insect infestation must be avoided. In addition, it is imperative that biodegradable plastics do not contaminate the recycling stream for non-biodegradable plastics.

Biobased materials can be classified into three main categories according to their method of production:

Category 1: Polymers directly extracted from biomass;
Category 2: Polymers produced by classical chemical synthesis from biomass monomers;
Category 3: Polymers produced...
directly by natural or genetically modified organisms.

Most of the commonly available Category 1 polymers are extracted from marine and agricultural products, examples including polysaccharides such as starch and chitin, and proteins such as casein, collagen and soy.

Of all the possible biopolymers that have been produced from biobased materials, polyactic acid (PLA) has shown the highest commercial potential and is now produced on a comparatively large scale. PLA is synthesized from lactic acid which can be produced cheaply by the fermentation of biomass such as corn or wheat, or waste products such as whey or molasses.

PLA can be made into films, co-extruded into laminates, thermoformed and injection stretch blow molded into bottles. The major application to date has been as food service containers. Other current uses are for thermoformed packaging for bakery products, and bags for bread, fresh pasta and salads.

Category 3 polymers consist mainly of the microbial polyesters poly(hydroxyalkanoates) (PHAs). They are produced from the fermentation of sugars by many bacterial species in the form of intracellular particles which function as an energy and carbon reserve. PHAs have good chemical and moisture resistance as well as good O₂ and aroma barrier properties.

PHAs are degraded on exposure to bacteria or fungi in soil, compost or marine sediment. Biodegradation starts when microorganisms begin growing on the surface of the plastic and secrete enzymes that break down the polymer.
Biodegradation of Mirel™ PHA cups in an industrial composting facility in California

WVTRs of starch-based films are 4-6 times greater than those of conventional films made from synthetic polymers. PLA has WVTRs four times higher than conventional films; PHAs has WVTRs similar to those of LDPE. The gas barrier properties of many biobased materials depend on the ambient humidity, the two notable exceptions being PLA and PHA. PHB has better O₂ barrier properties than PET and PP, and adequate fat and odor barrier properties for applications with short shelf life products.

The mechanical properties of most biobased materials are similar to synthetic polymers with PLA having mechanical properties similar to those of PET.

In the short term, biobased materials will be used for short shelf life foods stored at chill temperatures, due to the fact that the materials are biodegradable. Potential applications include fast food packaging of salads, egg cartons, fresh or minimally processed fruits and vegetables, dairy products such as yoghurt and organically grown foods.

One of the major limitations to the greater use of biobased plastics (apart from their cost) is their availability. The annual production of petroleum-based plastics used for packaging is 100 million tonnes; in 2008 production of biobased plastics for packaging was just 0.6% of this (600,000 tonnes). While production will increase rapidly over the next few years, it will be a long time before biobased plastics replace significant quantities of petroleum-based plastics.

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CHAPTER 6: SEALING PACKAGES

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6.1 Learning Objectives

This module has been written to provide a basic understanding of, and introduction to, the methods available for sealing packages. On completion of this module, the student will have a general appreciation of the major methods used to seal packages, specifically the use of closures on glass and plastic bottles and containers, and the heat sealing of films, pouches and bags.

6.2 Introduction

A closure is any device which is used to close a package and seal the contents inside. Closures are removed or opened to access the food or drink inside the package, allowing the product to be consumed. Closures include corks, lids, tops and caps are made mainly from metal or plastic.

Closures are required to perform some or all of the following functions without affecting or being affected by the contents of the package:

a. Provide an effective hermetic (air-tight) seal to prevent the passage of solids, liquids or gases into or out of the package;

b. Provide easy opening and (when only part of the contents is used at one time) resealing of the package;

c. Provide evidence of inviolability, i.e. that unlawful access to the contents or their exposure to the atmosphere has not occurred. Roll-on pilfer proof (ROPP) closures such as the aluminum roll-on closure used on beverage bottles leave a tell-tale ring around the bottom of the neck of bottles after opening; tamper-evident closures are designed to deter tampering with the contents by providing evidence of tampering.

6.3 Closures for Glass and Plastic Containers

6.3.1 Closure Terminology and Construction

The final, critical aspect of glass and plastic containers is the closure which can consist of a cap, lid or cork to seal the jar or bottle. Although glass is an excellent barrier to moisture vapor, gases and odors, an incorrectly designed or applied closure may negate the benefits that glass packaging offers in protecting food products from deterioration.

Closures are frequently referred to by the following terms:

a. the panel is the flat center area in the top of the closure;

b. the radius or shoulder is the rounded area at the outer edge of the panel connecting the panel and the skirt;

c. the skirt is the flat, almost vertical portion on the side of the closure which serves as the gripping surface and may be smooth, knurled or fluted;

d. the lug is a horizontal inward
protrusion from the curl which seats under the thread or lug on the finish of the container and holds the closure in position.

Closures are made from one of two materials: metal or plastic. Metal closures are stamped out of sheets of tinplate, ECCS or aluminum, generally with a thickness of about 0.25 mm. The sheets are usually coated with lacquers/enamels to prevent the metal from reacting with the contents of the container, and are frequently printed. Metal closures can take four forms: screw caps, crowns, lug caps and spin-on or roll-on closures.

Most closures for plastic containers and increasingly for glass containers are manufactured using plastics. The most commonly used polymers are the thermoplastics are high density polyethylene (HDPE) and polypropylene (PP) although low density polyethylene (LDPE), polystyrene and some copolymers are also used.

The actual sealing component of the closure is the gasket or liner which must make intimate contact with the glass finish to form an effective seal. Gaskets are made from rubber or plastisols, the latter being suspensions of finely divided resin (often PVC) in a plasticizer which can be flowed in or molded. Liners consist of a cushioning material (known as a wad) with a facing material, the purpose of the latter being to isolate the contents of the container from contact with the wad. Generally the wad is made of composition cork (granules of cork bonded together with either a gelatin-type glue or a synthetic resin) or paperboard and faced with either a coated paper, a paper faced with plastic film, a plain metal foil, a lacquered metal foil, or a metal foil faced with a plastic film or coated with a layer of a wax material.

Thermoplastic resins have allowed the development of ‘linerless’ plastic closures which rely on a variety of styles of sealing rings molded into the closure to effect a liquid or hermetic seal.

6.3.2 Food Container Closures

In general, closures which are used with food containers can be classified under four headings:

1. CLOSURES TO RETAIN INTERNAL PRESSURE

These closures are generally required to contain pressures from about 200 kPa to over 800 kPa as typically found in carbonated drinks and beer.

a. Crown Cork

The traditional pressure-retaining closure for glass bottles has been the crown cork, a crimp-on/pry-off friction-fitting closure made from tinplate with a fluted skirt (angled at 15° to maintain an efficient seal) and a cork or plastisol liner. Though simple in concept, the crown cork provides a friction-fit sufficient to seal pressurized beverages. The flared cap skirt in conjunction with the smoothness of the bottle neck provides easy access through the prying motion of a bottle opener. The crown cork of today is still much the same, except that the teeth on the skirt have been reduced from 24 to 21, ECCS is used rather than tinplate, and
some type of plastic material linings have largely replaced cork. A relatively recent improvement has been the introduction of twist-off crown corks.

The 26mm crown cork is used worldwide and is normally applied only to a glass finish. The corrugations of the crown can be crimped under the ring during application to hold the crown in place and form a solid seal. The twist-off finish has four non-continuous threads and the corrugations of the crown are crimped into the threads to form the seal. The crown can be removed from the twist container by turning 6 mm.

The crown cork is applied to a filled container using a crowner that exerts a straight downward force on the crown to crimp it onto the finish. The crowning head compresses the crown liner to form a tight seal and bends the crown skirt downward and inward to lock it tightly under the locking ring on a pry-off finish. Crowns are used in a wide range of beverage products as an inexpensive single use seal.

b. Roll-On Tamper-Evident (ROTE)

A roll-on tamper-evident (ROTE) also called roll-on pilfer-proof (ROPP) aluminum closure was first used in the 1920s as a closure on bottles of prescription drugs. It is now used where critical sealing requirements, such as carbonation retention, vacuum retention and hermetic sealing are to be met. The closure is produced as an unthreaded shell containing a liner and is applied to the proper finish on a plastic or glass container. A thread is formed in the closure matching the bottle thread. The ROTE closure is produced in a wide range of sizes (from 18mm to 38mm) and is available in two different tamper-evident styles: the vertically scored and the standard band (both with and without venting). On opening, the vertically scored band ruptures along vertical score lines and is removed as part of the closure. The standard band separates from the closure during opening and remains on the bottle. Both standard and vertically scored closures can be reclosed after the original opening by turning the threaded closure back onto the container finish.
The ROTE closure is produced from coated light gauge aluminum and a range of lining materials are available depending on the product to be packaged. The closure is coated on the inside surface for protective purposes and can be printed and decorated in various colors on the outside surface to enhance the package's appeal.

ROTE closures are applied to filled containers using roll-on capping machines. The capping head first applies a downward pressure that compresses the liner onto the sealing surface of the container. The capping head then forms a thread in the closure matching the container thread, while also tucking the tamper-evident band under a locking ring on the container finish.

Plastic versions of the closure are now available and widely used. The rolled-on or spun-on aluminum or plastic closure is especially popular for carbonated drinks in large containers where reuse is common. The same closures are applied to glass and plastic bottles.

Plastic prethreaded closures can generally be characterized by their size (diameter), thread form, material, seal and type of tamper evidence. The most common size by far is 28 mm. Increasing the size of the closure usually significantly increases the cost of both the closure and the bottle because more material must be used in both. However, some 38 mm caps are used for carbonated products especially where the convenience of drinking from the bottle is required.
2. CLOSURES TO CONTAIN AND PROTECT CONTENTS

These closures are designed to contain and protect the contents with no internal pressure, e.g. wine in a glass bottle. The most common closure for wine has been the traditional bark cork obtained from the holm oak tree *Quercus suber* which grows mainly in Spain and Portugal. The cork stopper has been used as a closure on glass bottles for many centuries and provides an incomparable friction-hold seal. With a high cellular density, cork is compressible, elastic, highly impervious to air and water, and low in thermal conductivity. However, 5-10% of all wines sealed with natural cork suffer from cork taint caused by TCA (2,4,6-trichloroanisole) taint, which can result in undesirable musty aromas and flavors, typically described as ‘wet cardboard’ odor.

The agglomerate cork, originally developed as a closure for sparkling wine, consists of small pieces or granules of clean, natural cork bound together with resin or a chemical binder into a single stopper, with one or more thin discs of intact natural cork stuck on the end intended to be in contact with the wine. The improvement results from an effective disinfecting or deodorizing process which extracts volatile components from the cork material. This, it is claimed, eliminates the possibility of contaminants being retained inside the lenticels (pores through which gases are exchanged between the atmosphere and plant tissues).
A challenge to the cork was the development in France in the late 1960s of an aluminum rolled-on closure known as Stelvin®.

The wad consists of three components: an expanded LDPE foam substrate to provide controlled and uniform compressibility, a layer of aluminum foil to provide a gas barrier, and a PVdC copolymer facing which isolated the aluminum foil from the product and provided an additional $O_2$ barrier as shown below:

The closure is now widely used in the Australasian wine industry and is gaining acceptance in many other wine-producing countries; it has eliminated the problem of oxidation and the risk of cork tainting and allows easy resealing of the bottle.

3. CLOSURES TO MAINTAIN VACUUM INSIDE CONTAINER

These closures are designed to maintain a vacuum inside a glass container which typically contains heat processed food. Three types of vacuum closures are used in food processing:

a. Lug-Type or Twist Cap

This can be removed without a tool and forms a good reseal for storage. It has three, four or six lugs and a flowed-in plastisol liner.

b. Press-On Twist-Off Cap

This has no lugs but the finish is threaded. The gasket is molded plastisol and covers the outer edge of the panel and the curl of the cap. It is widely used on baby foods. This type of closure is held on mainly by vacuum with some assistance from the thread impressions in the gasket wall.

c. Pry-Off (Side Seal) Cap

This is still widely used on retorted products. It consists of a cut rubber gasket held in place by being crimped under the curl. Like the preceding
closure, it is also held in place mainly by vacuum with slight assistance from the friction of the rubber gasket against the side of the container finish.

All of the above closures are made of metal (tinplate or ECCS) and are fitted either with flowed-in liners, gaskets or rubber rings. Vacuum closures often have a safety button or flip panel as shown above. It consists of a raised, circular area in the center of the panel that serves two purposes: it provides a visual indicator to the consumer that the package is properly sealed (containers with these types of closures usually have instructions on the closure warning consumers not to purchase or consume the product if the flip panel is up), and in the processing plant the flip panel aids in automatic on-line detection (using a so-called ‘dud’ detector) of low vacuum or no vacuum containers.

4. CLOSURES TO SECURE CONTENTS INSIDE CONTAINER

Some closures are designed only to secure the contents inside the glass container (e.g. peanut butter as shown below). They are frequently screw caps with a minimum thread engagement of three-quarters of a turn. They are made either from metal or plastic and typically have either a plastic-coated paperboard wad inside, or may be of the liner-less plastic style.

6.4 Heat Sealing

6.4.1 Introduction

The heat sealability of a packaging film is one of the most important properties when considering its use and the integrity of the resultant seal is of paramount importance to the ultimate package integrity. Heat sealable films are considered to be those films which can be bonded together by the normal application of heat, such as by conductance from a heavy heat-resistant metal bar containing a heating element. Nonheat-sealable films cannot be sealed this way, but they can often be made heat sealable by coating them with heat-sealable coatings. In this way the two facing coated surfaces become bonded to each other by application of heat and pressure for the required dwell time.

Heat seals can be of two types: fin seal or overlap seal. In a fin seal, the two inner surfaces are sealed together, whereas in an overlap seal, the inner surface is sealed to the outer surface.
A number of factors are involved in determining the quality of a heat seal. They can be conveniently summarized under three headings:

**Machine factors:** dwell or clamp time; temperature and pressure

**Resin factors:** density; molecular weight and additives in the resin.

**Film factors:** gauge; style or form (e.g. whether gusseted or not) and treatment for printing.

All of these factors tend to interact in a complex way. For example, the amount of heat available may be limited by the capacity of the heating elements, by the rate of heat transfer of the sealing bar and its coating, or the type of product being packaged. Increasing the dwell time (i.e. the time during which heat is applied) will increase the heat available, but this may prove to be uneconomic since fewer units will be able to be handled per minute.

### 6.4.2 Conductance Sealing

Conductance (also known as resistance or bar) sealers are the most common type of heat sealers in commercial use and typically consist of two metal jaws (often patterned or embossed to give the seals extra strength), one of which is electrically heated, the temperature being controlled thermostatically. The second or backing jaw is often covered with a resilient material such as rubber to distribute pressure evenly and aid in smoothing out the film in the sealing area. Frequently the unheated jaw is water cooled, although in some situations it may be heated to the same temperature as the first jaw to enable sealing through sheets of film in exactly the same way each time. A simple heat sealer is shown below:

Conductance sealers are used for coated regenerated cellulose films or any other materials with a heat seal coating such as foil or paper. However, they are not suitable for unsupported materials such as LDPE film which would simply melt and stick to the
jaws. Serrated jaws can be used to ensure that the two webs are stretched into intimate contact with high local pressure; they also improve appearance. For all sealing jaws a non-stick coating is desirable; PTFE (poly(tetrafluoroethylene)) also known as Teflon™ is commonly used, either as a cloth-reinforced film or, in the case of serrated jaws, as a powder bound in a heat-resistant vehicle.

Dwell time should be able to be controlled to fractions of a second and be easily adjustable. Likewise, the pressure between the jaws should also be easily adjustable. Both these factors will need to be changed when different materials are heat sealed. A variation on this type of sealer is the band sealer, where the films travel between two endless bands of metal which are pressed together by heated bars. The heat passes through the bands and seals the films; the bands are then pressed together by chilled bars to withdraw heat from the seal. Band sealers are widely used for sealing pouches and have the advantage of being continuous.

6.4.3 Hot-wire Sealing

This method of sealing (which uses a thin wire or strip of metal heated with a low voltage current) has found application for the manufacture of polyethylene bags and pouches in tubular form, the cutting and sealing operations being carried out in the one step. It is only applicable to thermoplastic films which can tolerate high temperatures for a short time and which also have a low viscosity in the fused stage. When unsupported films are trim sealed by this method, they tend to form a strong bead in their seal areas due to surface tension and orientation. This method is also used to a limited extent with laminated constructions.

There is a tendency with this method of sealing to get what is known as ‘angel hair’ - fine strands of polymer protruding from the seal area. This can be controlled with the use of proper temperatures and times. Generally films thicker than 0.05 mm are difficult to seal through, especially if they have gusseted structures.

6.4.4 Impulse Sealing

In this method the films (usually unsupported materials) are clamped between two cold metal bars and then fused by the effect of a short, powerful electrical impulse; cooling occurs under pressure. Much lighter jaws than for conductance sealers are used. A high current is sent for a short period through a nichrome resistance wire or ribbon covered with PTFE tape. The current heats the wire to the desired temperature, the temperature being controlled with a transformer.

Dwell time of the heating impulse must also be controlled, as must the length of the cooling period. Thus two timers are often found on impulse sealers, the second timer controlling the cooling of the resistance wire to allow the film to harden under
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pressure and prevent deformation of the film in the sealed area. Sometimes one of the jaws is water cooled to prevent excess heating and promote rapid cooling. If very heavy films are to be sealed, both jaws may contain resistance wires. To prevent the film from sticking to the heated jaws, it is usual to cover them with a slip sheet such as glass cloth impregnated with PTFE. Generally the seals produced by impulse sealing are of excellent quality.

Continuous heat sealers are typically most useful for small to medium sized package sealing. High throughput is the primary advantage of a continuous sealer as the machine can typically handle as many packages as the operator can feed into the belts. Continuous heat sealers are more complicated than impulse sealers as they contain more moving parts. The use of belts and a conveyor require a motor and gearing that adds cost and also may mean additional maintenance.

6.4.6 Induction Sealing

Induction sealing is a non-contact method of heat sealing made by exposing an aluminum foil coated with a thermoplastic adhesive substance to a magnetic field. The field induces eddy currents, which generate precise amounts of localized heat in the aluminum foil, melting the adhesive material without any physical contact between the coil and the package. Modern advances in solid state technology have made induction heating a remarkably simple, cost-effective sealing method.
The basic components of an induction heating system are an AC power supply and induction coil. The power supply sends alternating current through the coil, generating a magnetic field. When the package is placed in the coil, the magnetic field induces circulating (eddy) currents in the package.

Induction sealing is used to heat seal diaphragms or innerseals to bottles and jars. To be induction sealed, there has to be a thermoplastic heat seal layer laminated or coated onto aluminum foil (often there is a paper or plastic foam layer between the foil and the plastic). When the aluminum foil is heated by the induction coil, the heat is then transferred to the heat seal layer, which quickly reaches the melting point, and becomes an adhesive to bond the diaphragm to the bottle. An induction seal provides tamper evidence and a hermetic seal when used as an inner seal beneath a normal threaded closure. The torque of the cap holds the seal in place during the induction heating process.

Induction sealing is also widely used to heat seal both the longitudinal and transverse seals of laminated paperboard cartons containing aluminum foil. The induction system generates an eddy current in the aluminum layer inside the packaging material structure. The aluminum heats up and transfers heat to the LDPE layers that reach their melting temperature. After the sealing pulse is terminated there is a cooling time that enables the LDPE to re-solidify as a single layer, guaranteeing a strong and tight seal. The jaw pressure must be kept for sufficient time to allow suitable sealing and cooling, in order to ensure a tight closure of the package. After the end of the cooling time the seal is cut.