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Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 11: Processing and converting of thermoplastic materials

1. INTRODUCTION:

The first plastics were derived in 20th century from natural raw materials like coal, oil and natural gas. Polyethylene, most widely used plastic today, was invented in 1933 – it was used in packaging from the late 1940s in the form of bottles, crates replacing wooden boxes and film and extrusion coatings on paperboard for milk cartons.

Plastic films can be joined with other plastics by coextrusion, blending, lamination and coating to get properties which the components could not provide alone. 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, fresh produce trays and plastic sacks, and are used for returnable pallets, as an alternative to wood.

The plastic raw material, also known as resin, is usually supplied by the polymer manufacturer in the form of pellets. Some plastics in powder form are used in certain processes. While, some plastics are used to make coatings, adhesives or additives in other packaging related processes, the first 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 combining of high pressure, friction and externally applied heat. This is done by forcing the pellets along the barrel of an extruder using specially designed screw under controlled conditions that ensure the production of a homogeneous melt prior to extrusion. For the manufacture of film, the molten plastic is forced through a narrow slot or die. For the manufacture of rigid packaging, such as bottles and closures, the molten plastic is forced into shape using a precisely machined mould.

2. PROCESSING OF THERMOPLASTIC FILMS

Plastic films by definition are less than 100μm thick. Film is used to wrap product, to overwrap packaging, 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 used and the method of film manufacture together with any coating or lamination.

2.1 Film or Sheet Extrusion

Extrusion is one of the important plastic processing methods in use today. Most plastic materials are processed in extruders and commonly pass through two or more extruders on their way from the chemical reactor to the finished product. All of the thermoplastics are formed into sheet or film by the process of screw extrusion.

The heart of the extruder is the screw which rotates within a close-fitting and heated barrel. It is capable of pumping a material under specific operating conditions at a specific rate, depending on the resistance at the delivery end against which the extruder is required to pump. The extruder resembles a mincer into which granules are fed, heated and compressed until they fuse into a melt which is forced through a slot or circular die. Sufficient heat is produced by the energy of the screw to allow the process to continue with very little heat input.

There are basically two processes by which the extruded thermoplastic can be converted into film: the tubular process and the flat film process.

2.1.1 Tubular process

In the tubular or blown film process, a thin tube is extruded, and by blowing air through the die head, the tube is inflated into a thin bubble. Which is cooled, flattened out and wound up. The ratio of bubble diameter to die diameter is known as the blow-up ratio. Most low density polyethylene blown films used in packaging are made using blow-up ratios of between 2.0 and 2.5:1. Blown film extrusion can produce defects such as variations in film thickness, surface defects, low tensile and impact strength, haze, blocking and wrinkling.

The properties of the film depend strongly on the polymer used and the processing conditions. The higher the density, the lower the flexibility and the greater the brittleness.

The higher the molecular weight, the greater the tensile strength and resistance to film brittleness at low temperatures, but the lower the transparency.

2.1.2 Flat Film Process

In flat film or cast film or slit die extrusion, the molten polymer is extruded through a slit die into a quenching bath or onto a chilled roller. In both cases rapid cooling of the extruded film is most important. The ratio of the haul-off rate to the natural extrusion rate is referred to as the draw-down ratio. Draw-down ratios between 20:1 and 40:1 are typical.

The advantages of the flat film process include less thickness variation, very high outputs and superior optical properties. This latter advantage is a consequence of the quicker cooling which can be achieved in the flat film process where cooling is by conduction, compared with the tubular film process, where cooling is by convection.

2.1.3 Coextrusion

It is possible to extrude simultaneously two or more polymers which fuse at the point of film formation into a single web by using combining adaptors. Such a process is known as coextrusion and permits the production of a single web having, properties not possessed by any one of the component polymers. A two component slot die is capable of producing a two or three-layer film from two materials, while a three-component die can produce a five-layer film from three materials.

2.2 Solution Casting

Solution casting can be used where the best surface properties are desired in plastic film or sheet. The plastic granules or powder with any desired plasticizer, colorant, etc. are dissolved in a suitable solvent. After filtering, the solution is cast from a slot die onto a moving, highly polished stainless steel belt. The solvent is removed by controlled heating, and solvent-free, sparkling clear, flat film is taken off from the take-off section of the casting belt.

Some cellulose acetate, butyrate and propionate films are produced by solution casting, as well as ethyl cellulose films. Other materials which can or have been made into film or sheet by this technique are PVC, vinyl chloride/vinyl acetate copolymers, polycarbonate and PVA.

2.3 Orientation

Orientation of thermoplastic film is a process of stretching the material in such a manner as to line up the molecular chains in a predetermined direction. Once lined up, the ordered arrangement is frozen in the strained condition. Biaxially oriented films possess higher tensile and impact strengths, improved flexibility, clarity, stiffness and toughness, and increased shrinkability. Gas and water vapour permeability may also be reduced, generally by 10 to 50% depending on the type of polymer, and the degree and temperature of orientation.

The most common method used to orientate a thermoplastic film is to stretch it after it has been heated to a temperature at which it is soft. This temperature is below the flow temperature at which the molecules would glide readily past one another when the material is stressed, but above the glass transition temperature. As a result of this stretching, the direction of the molecules changes towards that in which the material is stressed, and the molecules are extended like springs. The temperature is then dropped below the softening point of the material while the molecules are held in this configuration, so that the molecules are frozen in the strained position.

2.4 Lamination

Although lamination is the process of bringing two or more webs together and bonding them with an adhesive or by heating. A laminate is defined as any combination of distinctly different plastic film materials or plastic plus non-plastic materials like paper, aluminium foil and regenerated cellulose, where each major web is generally thicker than six microns, regardless of the method of manufacture. There is no upper limit to the possible number of webs, but two is the obvious minimum and one of these must be thermoplastic.

There are two main techniques employed in the fabrication of laminates: adhesive lamination and extrusion coating. The associated technique of coating without extrusion is an important process for modifying film properties, as well as a means of applying the adhesive in adhesive lamination. There are two types of coating processes. In one an excess coating is applied to the web and the surplus is removed; in the second a pre-determined amount is applied to the web using rollers or other equipment.

Nitrocellulose and vinylidene chloride/vinyl chloride copolymer are common surface coatings used, but synthetic resins, acrylics and many other formulations are used for varnishing, barrier formation and heat sealing. A recent trend is towards the use of cold seal coatings which are based on latex. They require only contact pressure for two coated surfaces to adhere, and permit packaging machine speeds to be considerably increased. In addition, damage to heat-sensitive foods such as chocolate-coated confectionery is avoided.

3. PROCESSING OF RIGID THERMOPLASTIC PACKAGES

3.1 Blow Moulding

It is a process to produce hollow objects and was practiced with glass in ancient times, and the basic techniques have been derived from those developed by the glass industry. Today a wide range of blow moulded bottles and containers is produced for use in food packaging.

In blow moulding a molten tube of thermoplastic known as a parison is surrounded by a cooled mould having the desired shape. A gas is introduced into the tube causing the molten mass to increase against the walls of the mould where it solidifies on cooling. The mould is then opened and the bottle ejected.

Normally the process consists of three stages: melting the resin, forming the parison, and blowing the parison to produce the final shape. The blowing step may take from a few seconds to more than a minute for large shapes; the rate limiting step is cooling of the moulded shapes.

There are two techniques of plasticizing resin and forming the parison:

1. Extrusion, which produces a continuous parison that has to be cut in required length; this is the most common method used.
2. Injection moulding, where the parison is formed in one mould and then transferred into another mould for blowing.

3.1.1 Extrusion Blow Moulding

In the simplest method of extrusion blow moulding, a mould is mounted under the die and the parison extruded between the open halves of the mould. When the parison reaches the proper length, the extruder is stopped and the mould closes around the parison. A blow pin fixed inside the die head allows air to enter and blow the parison into the final shape. The shape of the bottle or jar is defined, but the distribution of material and wall thickness is less well controlled. The cycle restarts after the part has cooled and the mould opened.

Extrusion blow moulding is widely used with HDPE, PP, PVC and acrylonitrile copolymers. The common grades of PET cannot be extrusion blown.

A development in the production of co-extruded bottles, where two or more extruders, each handling a different plastic material, produce a multi-layer parison having the desired properties. For example, a high-barrier, high cost material might be sandwiched between layers of a relatively low cost material to give a bottle with the desired barrier properties at an economical price.

3.1.2 Injection Blow Moulding

Injection blow moulding is a non-continuous cyclic process, and most closely bear a resemblance to the blowing of glass bottles. The parison is formed in one mould and then, while still molten, is transferred to a second mould where blowing with compressed air forms the final shape. The mould is opened and the bottle is ejected after cooling. Several moulds must be needed if the injection moulding machine is to operate near full capacity. The major advantage of injection blow moulding over extrusion blow moulding is that the process is virtually scrap-free, the finished parts usually requiring no further trimming, reaming or other finishing steps. In addition, the dimensions of the bottle show very slight variation from bottle to bottle, and with some materials, improved strength and clarity are attained due to the effect of a limited degree of biaxial orientation.

The resins most commonly used for injection blow moulding are HDPE, PP, PS, and PVC. Recently, PET has been injection blow moulded, and is likely to replace PVC in some applications.

3.1.3 Stretch Blow Moulding

Stretch blow moulding or biaxial blow moulding is a process where bottles with appreciable orientation in both longitudinal and transverse directions are produced. To produce a biaxially moulded bottle, a parison is stretched longitudinally under heat and blown into a bottle with consequent transverse orientation.

Stretch blow moulding is particularly important in the field of carbonated beverage packaging using PET bottles, but is limited to relatively simple bottle shapes. For best results the resin molecules must be conditioned, stretched and oriented at just above the glass transition temperature where the resin can be moved without risk of crystallization.

The reheat blow moulding method using two stages is the most widely used of the various stretch blow moulding methods. First the parisons are injection moulded in a completely separate stage and stored at ambient temperature until required. They are reheated to 90 to 110°C and then blown to their final shape. No stretch occurs at the top and bottom of the bottle. Typical stretch ratios for a 2 litre PET bottle are 2.3:1 in the axial direction and 3.9:1 in the hoop or transverse direction.

PET is the major stretch blown resin, but PVC, PP and acrylonitrile resins are also stretch blow moulded.

3.2 Injection Moulding

The injection moulding process consists of softening material in a heated cylinder and injecting it under high pressure into a relatively cold mould where solidification takes place. It is a major method for converting thermoplastics and is widely used for producing tubs and jars used for packaging yogurt and margarine, as well as various caps, spouts and dispensers. It is also used to produce retortable plastic containers from polypropylene. The injection moulding process occurs in three consecutive steps:

1. Feeding and thermally plasticizing granules by means of an extrusion-type screw that rotates until the required amount of melt has been conveyed to the front of the barrel.
2. Injecting a calculated amount of stock into a cold cavity.
3. Cooling and ejecting the moulded components.

High production rates are possible, and because injection moulds are expensive, short production runs are uneconomic. Resins which are generally injection moulded include low and high density PE, PP and PET, the latter as a preform for stretch blown beverage bottles.

3.3 Compression Moulding

This is one of the oldest methods of moulding thermoset resins, i.e. plastics that in their formed or cured state are infusible and insoluble owing to cross-linking. It has been used for many years in food packaging for the production of screw caps from urea formaldehyde for bottles and jars.

In compression moulding a pre-set amount of resin is placed in the lower half of a heated mould. The top of the mould is then brought down into the matching bottom cavity, and heat and pressure are applied, causing the plastic to melt and flow until it fills the mould. After setting the mould is opened and the moulding ejected. There has been a revival of interest in thermoset resins and compression moulding because of the demand for ovenable packages, like for frozen meals that can go from the freezer directly to an oven, and then to the table.

3.4 Thermoforming

In this process, a sheet of generally 75 to 200 mm thick is heated to its softening temperature, commonly by means of an infra-red radiant panel heater. By some pneumatic or mechanical means, the sheet is forced against the mould shapes and, after cooling, the part is removed and trimmed. Typical thermoplastics used for thermoforming include PS, PVC, cellulose acetate and polyamides.

There are three main techniques for thermoforming:

1. Vacuum forming, in which the sheet is placed over a mould and heated from above until soft. A vacuum is created between the sheet and the mould and atmospheric pressure above the sheet forces it on to the mould where it is cooled sufficiently to retain its shape.

2. Pressure forming which is identical to vacuum forming except that a positive air pressure is applied to the sheet from top, which forces the softened sheet onto the mould. The pressure differential able to be obtained by this method can far exceed that obtained using vacuum forming.

3. Matched mould forming where heated sheet is pressed into shape by trapping it between matched male and female moulds.

The first two techniques result in thinning of the sheet and substantial reduction in barrier properties, in inverse proportion to the square of the increase in area. The deeper the draw, the less uniform the wall thickness and barrier properties.

Thermally stable PET containers are common for dual ovenable applications for chilled, frozen and retortable foods, shelf stable applications where the food can be reheated in the package using either a microwave or conventional oven. These containers are known as crystallized PET or CPET and are stable at temperatures up to 230°C. Amorphous PET begins to soften at temperatures over 63°C.

The CPET process is based on orthodox reheat thermoforming, in which an extruded PET sheet containing an added nucleant material is reheated to around 170°C where it softens. It is then thermoformed into a hot mould and held for a crystalline structure to develop for long period. It is then transferred into a second mould where it is cooled.

3.5 Plastic Foam

Foamed plastics have been used widely since 1940s, due largely to their desirable properties which include a high strength to weight ratio, good insulating and cushioning properties. A wide range of plastic polymers can be foamed, comprising low and high density PE, PP, ethylene copolymers, cellulose acetate, PS and PU. The market is dominated by the last two polymers, with PS being used in preference to PU for food contact applications.

Cell formation is initiated by foaming agents. Physical foaming agents are compounds that change their physical state during cell growth and most important are volatile liquids with boiling points below 110°C at atmospheric pressure. Chemical foaming agents decompose under heat to at least one gaseous decomposition product, usually nitrogen.

PS foams can be formed by two processes: injection moulding and extrusion. For injection moulded foam, machines resembling normal injection moulding machines are used except that steam is injected to heat the foaming agent containing beads. Extruded PS foam is produced by free expansion of hot PS, blowing agents and additives through the slit orifice of a high L/D ratio extruder to about 40 times the pre-extrusion volume. The amount and type of blowing agent control the density of the foam produced.

4. Conclusion

There are various methods for conversion and formation of thermoplastic packaging materials like extrusion, Lamination or coating, blow moulding, injection moulding, orientation, thermo forming etc. Each method has its typical characteristics, advantages and disadvantages. Research focus is now on newer methods of thermoplastic conversion which are fast and efficient and also includes recycled feed stack generated as waste during formation of various shapes.

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