Ecodesign In Food Packaging

UNIT 8: Plastics in food packaging

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After learning this unit, the student will be able to:

– Know the main types of plastics used in food packaging;
– Learn the importance and possibilities of recycling, reuse of plastic waste;
– Know basics of technologies for obtaining plastic packaging;
– Be able to use the design knowledge of plastic packaging in the current activity of eco-design

Funded by the Erasmus+ Programme of the European Union

Ecoinnovation Skills for European Designers, Project number: 562573-EPP-1-2015-1-SI-EPPKA2-SSA. Disclaimer: The European Commission support for the production of this publication does not constitute endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein

8.1 Definitions, classification, plastics used in food packaging

Plastic is a synthetic material made from a wide range of organic polymers, such as, polyethylene, PVC, nylon, etc., which can be molded into various shapes and then fixed in a form that is rigid or elastic.

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

• they are flexible and can mold under certain conditions, for the manufacture of the sheets, different forms and structures;

• they are generally chemically inert, though not necessarily impermeable;

• they are cost effective and meet the needs of the market;

• are lightweight;

• provides options in terms of transparency, color, thermal insulation, resistance to heat and barrier properties.

There are two broad categories of plastics: thermoplastics and plastics materials thermosetting. Termoplastele can be heated to form the product and then if these final products are reheated, the plastic will soften and melt again. On the contrary, the heat-insulating materials can be melted and formed, but once formed, after they have solidified, they stay solid and, unlike thermoplastics, can not be cast again.

Advantages thermal insulation (thermoset):

a) more resistant to high temperatures than termoplastele;
b) the design extremely flexible;
c) can achieve thick walls or thin walls;
d) excellent aesthetic appearance;
e) high levels of dimensional stability;
f) lower cost compared to termoplaste.

Advantages termoplaste:

a) high recyclable;
b) are aesthetically superior;
c) high resistance to impact;
d) capability of being poured again in different forms;
e) chemical resistance;
f) options on the surface, can be crystalline or rubbery;
g) organic production.

Disadvantages insulation:

a) can not be recycled;
b) more difficult to finish;
c) cannot be cast again or remodeled.

Disadvantages termoplaste:
a) generally more expensive than the heat-resistant;
b) it can melt if heated by accident**.**

In UNIT IV, we have presented the concepts on EU legislation related to packaging materials, plastic, plastic recycled, plastic films, also, we presented the concepts related to the properties relating to barrier and migration (see also annexes 1 and 3 of UNIT IV).

The types of polymers used for food packaging features:

- **Polyethylene - polyethylene (PE);**
- **Polypropylene;**
- **Polypropylene (PP);**
- **Polyesters - polyesters (PET, PEN, PC) (note: sometimes the PET's mark and PETE);**
- **Polyvinyl chloride - polyvinyl chloride (PVC);**
- **Polystyrene - polystyrene (PS);**
- *Ionomers – ionomers;*
- *Ethylene Vinyl Acetate - the Acetate of ethylene-vinyl - ethylene vinyl acetate (EVA);*
- *Polyamides - polyamides (PA);*
- *Polyvinyl chloride-fluoride - polyvinylidene chloride (PVdC);*
- *Butadiene styrene - styrene butadiene (SB);*
- *Acrylonitrile Butadiene Styrene - acrylonitrile butadiene styrene (ABS);*
- *The ethylene – vinyl alcohol - ethylene vinyl alcohol (EVOH);*
- *Polymethyl pentane - polymethyl pentene (PMP or TPX);*
- *Polymers nitrilici of the high-polymerization - high nitrile polymers (HNP);*
- *Fluoropolymers - fluoropolymers (PCTFE/PTFE);*
- *Materials based on cellulose - cellulose-based materials;*
- *Polyvinyl acetate - polyvinyl acetate (PVA).*

All the above materials are termoplaste. In the EU, constitutes 56% of the total plastics used, PP,PET,PS (including expanded polystyrene EPS) and PVC, comprise the bulk of the rest. The other plastics mentioned are used for improving the properties of the barrier, sealing in the heat, joining, or hot resistance.

It will characterize here the plastic materials, PP, PET, other features of the rest of the materials you find in the annex 2.

Poliester:

- Polyethylene (PE) - It is the most used polymer on the tonnage and cost efficiency. The conditions for processing controls the degree of branching in the polymer chain and, therefore, the density and other properties of the films and other types of packaging. Seals well heated, the films made from PE present a good barrier to moisture and to water vapour, but not at the O2, CO2 and other gases, however, the barrier properties increase with the density of the material. Has a melting point of 120 0C, which also increases with density. Types of polyethylene used: LDPE – low-density (low density PE) manufactured in general in films of 30 µm, LLDPE – linear LDPE film (linear low-density PE the film), has a polymer chain shorter and has superior properties regarding resistance to tearing and impact. MDPE or film PE the medium density (medium-density PE the film) has a mechanical strength higher than LDPE. LDPE can be co-extruded with MDPE to combine the proper tightness of the LDPE with the resistance of MDPE, for example. for coating by extrusion of the envelopes for soup mixes dehydrated. HDPE or PE high density is the most resistant polymer and can be extruded into films (foils) thin. This film is used for the applications of type "boil-in-the-bag". To improve the ability of sealing, HDPE may be co-extruded with LDPE. HDPE is injection molded closures, boxes, pallets and drums, and can be molded rotary knob for containers with volume intermediate. A major application of HDPE are containers of milk, molded by blowing, with a capacity of 0.5-3 l;

- Polypropylene (PP) - The polymer is a resin tougher and more dense than and more transparent in its natural form. PP has the lowest density and the highest melting point of termoplasticile used on a large scale and has a relatively low cost. Plastic has many applications for the packaging of food products such as flexible film and rigid form. High melting point of PP (160 ° C) makes it suitable for applications where is required the heat resistance, for example in the packaging of hot fill and microwave oven. PP can be laminated by extrusion with the PET or with other films resistant to high temperatures for obtaining strips of heat-sealing that can withstand temperatures of up to 115-130 ° C, for sterilization and use in bags retort. Unlike ON, the film cast becomes brittle even below 0 ° C and voltage cracks apear below -5 ° C and, therefore, should not be used if the application requires freezing. The film OPP or BOPP (Oriented PP film), on the other hand, is suitable for use for storage by freezing. Films OPP does not weld readily together by heating, because the melting temperature is close to temperature of shrinkage of the film. However, the OPP covered with acrylic has a good operation, including heat sealing. The acrylic coating also provides a good barrier to odors. A barrier to improved gas and water vapor is obtained by coating with PVdC - polyvinyl chloride-vinylidene (Polyvinylidene chloride). PP and PE have the lowest values of the surface tension and requires an additional treatment to make them suitable for printing, coating and lamination.

This is achieved with electric current of high voltage discharge (corona), treatment with ozone or by jets of gas. These treatments are easy oxidation of the surface and, therefore, improve the adhesion or fixing of coatings, inks, printing and adhesives. The range of food products packaged in films PP includes, biscuits, crisps(potato chips) and snacks, chocolate and confectionery, ice cream and frozen food, tea and coffee. The film metallised, PP, can be used for snacks and crisps (chips) in which it is necessary a barrier higher or a longer duration of storage. The cardboard can be covered by extrusion with PP to be used in the packaging of frozen / chilled foods to the trays which can be heated by the consumer in the microwave and in the oven. The applications of the major food of the PP are for pots and tubes, injection moulded for yogurt, ice cream, butter and margarine;

- **Polyethylene terephthalate** (PET or PETE) - PET it is a polyester resulting from the polymerization of terephthalic acid with the alcohol ethylene glycol. It can be: blown, injected into molds, foamed, coated by extrusion on the cardboard or extruded into sheets for thermoforming, can be oriented in biaxial (see also paragraph 8.3). The film thickness is between 12 µm, for films of the polyester up to 200 µm from the films of the composite made by lamination. PET films dont use additives. Pet has a higher resistance than other polymers, and by the orientation of the fibers acquire high resistance to breaking. Has more radicals that bind with other chemicals, giving the surface greater reactivity with the inks. PET melts at a high temperature of 260 0C and does not shrink below 180 0C. This makes the PET to be good for use in high temperature applications such as: sterilization with steam's"boil-in-the-bag" and for baking or reheating in the microwave oven or the conventional. The film is flexible to -100 0C. It can be laminated with PE to obtain good properties for heat-sealing. Also, the use of the coating with the PCdC offers a good resistance of the barrier and the capacity of heat-sealing. It is a barrier medium for O2, but by metallization with aluminum foil exhibits high barrier properties for O2 and water vapour and is used like the bags of coffee with the vacuum, and laminated on both sides with EVA is used in the bags for liquids having properties of high sealing. Paperboard extruded with PET is used to manufacture trays for heating food. PET is used in the manufacture of bottles for all carbonated beverages and mineral waters;

– **Another polyester is polyethylene naphthalene dicarboxylate** (PEN) - It is resistant to UV and is more resistant to temperature than PET. Can be manufactured as film and blown in the mold as the glass, you be used as monopolimer or copolymer with PET;

– **Polycarbonate** (PC) - It is a polyester that contains a group of carbonate in the structure. Mainly it is used as a substitute for glass, heat-resistant and very tough and durable. In the past it was used for milk bottles returnable, cooking trays for frozen food and if it is co-extruded with nylon could be used for carbonated beverages;

–**Polyvinyl chloride** (PVC) - PVC non-plasticized (UPVC) has useful properties, but it is a hard material, brittle, and the change is necessary for it to be used successfully. Flexibility can be achieved by the inclusion of plasticizers, low friction surface with the slip agents, various colors by adding pigments and improve the temperature of the processing by the addition of stabilizing agents. Great caution in the choice of additives used in the film that will enter in direct contact with food, in particular with regard to the migration of components of packaging in food products. The rigid UPVC is used for transparent or colored tray compartments for chocolate and biscuits. It is used with MAP for thermoformed trays to pack salads, sandwiches and cooked meats. Most PVC films are produced by extrusion. It can be oriented to produce a high-shrinkage film. Up to 50% shrinkage is possible at fairly low temperatures. Printed PVC can be used for hot-seal labels on plastic or glass containers;

– **Polystyrene** (PS) - PS has many packaging uses and can be extruded as a monolayer film co-extruded as thermoformable, injection molded and foamed film to provide a range of packaging types. It is also co-polymerized to expand its properties. It has good transparency. It is stiff, with a characteristic curl, suggesting freshness. A white pigmented film is used for the labels. The movie is printable. It has low barrier properties for water vapor and common gas, is suitable for packaging fresh products that need to breathe. The main disadvantage is that PS gives rise to a rigid or semi-rigid and fragile container. Therefore, it can be mixed with a butadiene styrene copolymer, SB or SBC. The mixture is known as high impact polystyrene or HIPS. Mixing produces a tougher material. It is translucent and is often used in pigmented white form. The HIPS plate may be thermoformed for short shelf life of dairy products. HIPS is also used in the extrusion of multilayer sheets with a variety of other polymers, PE, PP, PET, PVdC and EVOH. Food products packaged with these materials include dairy products such as yogurt cream and desserts, UHT milk, cheese, butter, margarine, jam, fruit compote, fresh meat, pasta, salads etc. Many of these products are aseptically packed with thermoforming, filling and sealing machines[1].

Additives: Plastic products would be a commercial failure without additives. These are organic or inorganic chemicals that allow the processing of plastics, the shaping of their use and the enhancement of their end-use performance. The plastic composition may range from 0.05% to 20% by weight of additives. Additives are classified by their function and not by the chemicals they contain and are used in compliance with EU environmental legislation and rules. About 75% of all additives are used in PVC. Additives that are applied to modify the properties of plastics account for about 70% of their total, 23% apply for the expansion of their properties, and about 7% to help with plastics processing[2].

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[1] RICHARD COLES, DEREK MCDOWELL, MARK J. KIRWAN FOOD PACKAGING TECHNOLOGY, Blackwell Publishing Ltd, 2003

[2] Plastic Packaging edited by Otto G Piringer & Albert L. Baner

8.2 Recycling of plastics

8.2.1 The Importance of recycling

Plastics are used today very commonly but have a long lifetime of over 500 years of environmental resistance without decomposing. That's why recycling and recovery of these materials at the end of their product life has become an essential factor required by the EU. Plastic packaging is eminently recyclable and a growing range of plastic packaging incorporates recycled material. EU legislation now permits the use of recyclable plastics in new packaging for food. Recycling a ton of plastic bottles saves 1.5 tons of carbon and a plastic bottle saves enough energy for a 60 watt bulb for 6 hours[3].

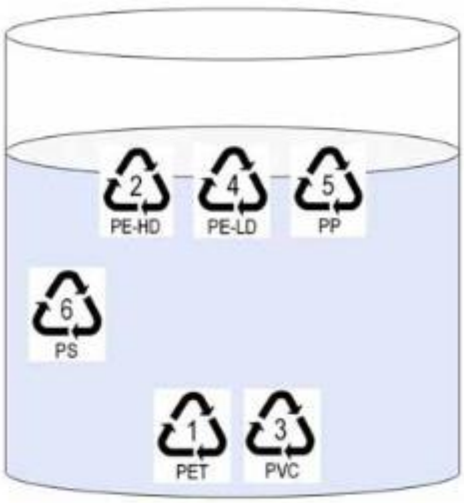
The use of mono-materials or mixed materials of the same type are the materials suitable for the recycler, and combinations of different types of plastic with similar densities should be avoided whenever possible. The goal is to minimize the number of plastics used and to specify which plastics can be recycled together or easily separated in the recycling process. It is recognized, however, that in order to provide both the required technical properties and the needs of the users, a combination of different types of materials is sometimes required.

Under these conditions, different density materials should be used to facilitate the separation of incompatible materials during chopping or mechanical crushing, or subsequently in the washing process. Combinations of different types of plastic of the same density should be avoided.

- PET is harder than water and will sink. In the PET washing process, caps or labels made from polypropylene (PP) or high density polyethylene (HDPE) will float and can be easily removed.
- Fillers that modify plastic density should be avoided and / or their use minimized as they reduce the quality of the recycled material.
- PVC PET contamination is a potentially important problem because these two polymers have close densities being heavier than water. The presence of very low levels of PVC (ca50-200ppm) in recycled PET causes a significant deterioration in chemical and physical properties and can compromise large quantities of recycled PETs for most recycling applications. For this reason, the use of PVC components of any kind in the manufacture of PET containers should be scrupulously avoided. These components generally include interlocks, seals, labels, sleeves and safety seals.
- Use of PLA (a biodegradable material) with PET should be avoided. The two polymers are incompatible and cannot be easily separated (both have a density> 1 g / cm 3). The presence of very low levels of PLA in PET causes container opacity and a

[3] Plastics packaging / www.bpf.co.uk

deterioration of the physical properties of recycled PET. In addition, PLA causes processing problems in the dryer because it melts at the drying temperature[4].



Specific gravity of various plastics

Plastics	Specific gravity
LDPE	0.91~0.93
HDPE	0.94~0.97
PP	0.90~0.91
PS	1.04~1.07
PVC	1.35~1.45
ABS	0.99~1.10
Polyester	1.38~1.39
PC	1.2
Nylon 66	1.13~1.15
Teflon	2.1~2.2

Source: "Polymer dictionary" by Taiseisha Co., Ltd (1970)

Fig 1.: The densities of polymers used in packaging.

8.2.2 System plastics identification SPI

In order to facilitate the correct sorting of bottles and plastic containers, which are frequently found in residential waste, for recycling purposes, the Society of Plastic Industry (SPI - The Society of Plastics Industry) in 1988 created the symbol system for identifying SPI Resin Identification Symbol System (SPI), also known as the plastic coding system for plastic containers. To facilitate visual identification of the plastic type during manual separation, the container and plastic cover must bear a material identifier (symbol). The symbol must be visible and preferably poured on the surface of the container or, in the case of films, repeatedly printed on the material. Identifiers generally have to be graded at the base of the container. Exceptionally, the identifier can be located near the base or printed on the label. Table 1 shows the seven categories of plastic symbolized by SPI.

The first six categories indicated represent about 90% of all the plastics produced. About 8% of plastics used are the so-called "engineering plastics" 'whose mechanical properties and loading capacity have been increased. Examples: Polyamide (PA), Polycarbonate (PC), Acrylonitrile butadiene styrene (ABS), Styrene acrylonitrile (SAN), Polyester, etc.[5] See also point 8.1 and Annex 2.

[4] PETCO_Design_4, Plastics packaging recyclability by design – Recycling guide www.petco.co.za
[5] Plastics Tehnologies practice, IC Professional trening series, August 2009

Tab. 1: Plastics symbolized by SPI symbols:

SYMBOL SPI	CHARACTERIZATION	RECYCLING
 PET/PETE	PLASTIC # 1 - POLYETHYLENE TEREPHALATE - PETE or PET - Containers made of this plastic sometimes absorb smells and flavors from foods and beverages that are stored in them. They are used for: soft drinks, water and other beverage bottles, peanut butter and other containers for detergents and cleaning containers etc.	PET waste is recycled into: new bottles, polyester for fabrics and carpets, car bumper filler and sleeping bag and jacket fibers.
 HDPE	PLASTIC # 2 - HIGH DENSITY POLYETHYLENE - HDPE POLYETHYLENE - HDPE products are very safe and there are no known cases of transmission of chemicals in food or beverages. They are used for: milk and water containers, some plastic bags, detergent containers, shampoo and motor oil, etc.	Transparent HDPE containers are easy to recycle in new containers. Colored HDPE waste is converted into plastic lumber, garden curbs and lawns, pipes, ropes, and toys.
 PVC/V	PLASTIC # 3 - POLYVINYL CHLORIDE - PVC OR V - The monomer content of vinyl chloride by which PVC is polymerized is recognized as a carcinogen and has been drastically limited, besides other dangerous chemicals are commonly used as PVC additives, which are not chemically bound, and can therefore infiltrate during use and disposal as waste. The most common plasticizer (DEHP phthalate) is suspected of being carcinogenic. Phthalic acid diluents are global contaminants and over 90% are used only for PVC production. Greenhouse plastic sheets contain DBP phthalate, which 200 pips (one trillion gram) per liter can kill the plants. This type of plastic should come into contact with food. It is used as a wrapping film due to tensile strength. In food packaging this material tends to be replaced.	Recycling is not technically and financially feasible. Thermal recycling can not be done due to the particularly dangerous noxes emitted by PVC heating. Pressure recycling is used. Currently, only 3% is recycled, old PVC products requiring mixing with virgin material to recreate quality material. Most of the collected waste is used for inferior quality products such as park benches or road noise barriers.
	PLASTC # 4 - Low-Density Polyethylene-LDPE Polyethylene - LDPE is not normally recycled but is recyclable in certain areas. It is a very healthy plastic that tends to be both durable and flexible. Stretch-wrapped food packaging films, sandwich bags, frozen	Recycled LDPE is used to make garbage cans, timber, furniture, etc.

LDPE	foods, pressure bottles, and plastic food bags are made from LDPE.	
PP	PLASTIC # 5 – POLYPROPYLENE - PP - is not commonly recycled, but is accepted in many areas. This type of plastic is strong and can usually withstand higher temperatures. Among many other products are used, wrapping films, margarine containers, yogurt boxes, syrup bottles, etc. Plastic caps are often made of PP.	PP has difficulty in recycling. Thus, obtaining different materials on the type or quality is difficult to achieve. Recycled PP is used to make ice scrapers, rakes, battery cables, etc.
PS	PLASTIC # 6 - POLYSTYRENE - PS POLYSTYRENE - Styrofoam. It is usually recycled, but it is difficult to do so and often gets into landfills. Two forms are used: Rigid polystyrene for CD cassettes, cutlery; Polystyrene formed (Styrofoam) used in food containers, packaging, insulations, egg cartons, disposable cups, plastic food cans, packing foam and peanut packaging.	It sinks into the water, does not drop when exposed to flame and produces black, dirty smoke and a burning smell when the temperature of the flame increases. Although its theoretical recycling is possible, it is still not economical. PS Recycle is used to make insulations, license plate frames, rulers, etc.
Other	OTHER - The SPI code 7 is used to designate different types of plastic that are not defined by the other six codes. Polycarbonate and Polylactic Acid (PLA) are included in this category. Polycarbonate or PC is used for baby bottles, large bottles of water, compact discs and medical storage containers. Recycled materials in this category are used, among other products, for the manufacture of plastic lumber. Polylactic acid is a thermoplastic aliphatic polyester produced from renewable resources, such as corn starch (in the United States) or sugar cane in the rest of the world.	These types of plastics are hard to recycle. PLA is biodegradable in the presence of oxygen, and is hard to recycle.

Some publications provide useful guidance on the safety of the use of plastics. So[6]:
1 PETE (Typical polyethylene terephthalate) Typical water bottles, soda and juice not intended for re-use or storage due to the possibility of bacterial build-up, if you reuse them, make sure that you have cleaned them properly. Generally, plastics considered safe for food and drink are:

[6] http://modernsurvivalblog.com/preps/safe-plastics-for-food-and-drink/

2 HDPE (high density polyethylene) food grade;
4 LDPE (Low Density Polyethylene);
5 PP (polypropylene).

Materials considered dangerous are not safe for food and drink. They may infiltrate or contain hazardous ingredients:
3 PVC (polyvinyl chloride) carcinogen during manufacture and incineration;
6 PS (polystyrene) possibly carcinogenic;
7 Other (usually polycarbonate, sometimes labeled, PC can infiltrate BPA (Bisphenol-A), a synthetic organic compound used in plastics, has hormone-like properties and is not suitable for use in food packaging. it is forbidden to use this plastic on bottles intended for children.). For the practical determination of the material when the symbol is not known, http://www.northstarrecycling.com/sorting-plastic-for-industrial-recycling/ proposes the two tests of FIG. 2.

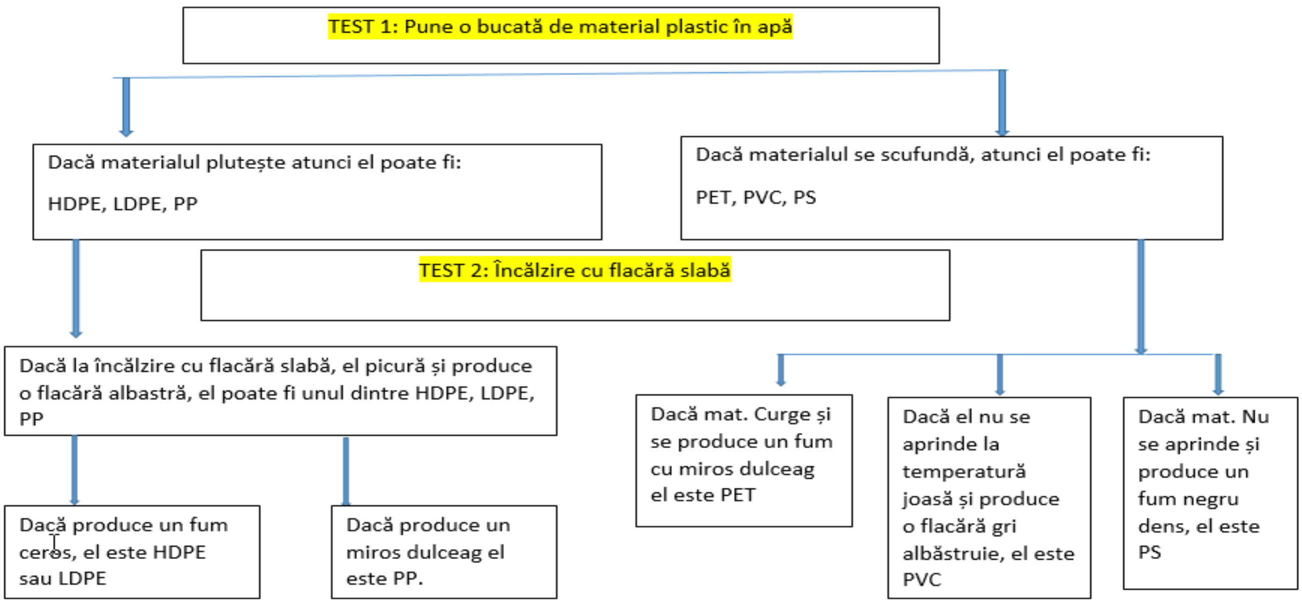


Fig. 2: Proposed tests for the determination of plastic material in the absence of the symbol.

8.3 Technologies of plastic packaging

It will present a few of the technologies used in the manufacture of plastic food packaging. A more detailed presentation in annex 1.

The key technologies for obtaining the packaging of the polymers are:
- extrusion;
- injection;
- compression.

8.3.1 Extrusion

The plastic raw material, also known as resin, is supplied by the granular or powder-form manufacturer. While some plastics are used to make coatings, adhesives, or additives in other packaging processes, the first important step in converting plastic resins into films, sheets, containers, etc. is to transfer the solid-phase granules to the liquid or melt phase in an extruder.

Plastic is melted by a combination of high pressure, friction and external heat applied. This is done by pressing the granules along the cylinder of an extruder using specially designed screws of polymers under controlled conditions which ensure the production of a homogeneous melt prior to extrusion. The molten plastic is finally pressed through a molding of the finished product to the technological lines of use.

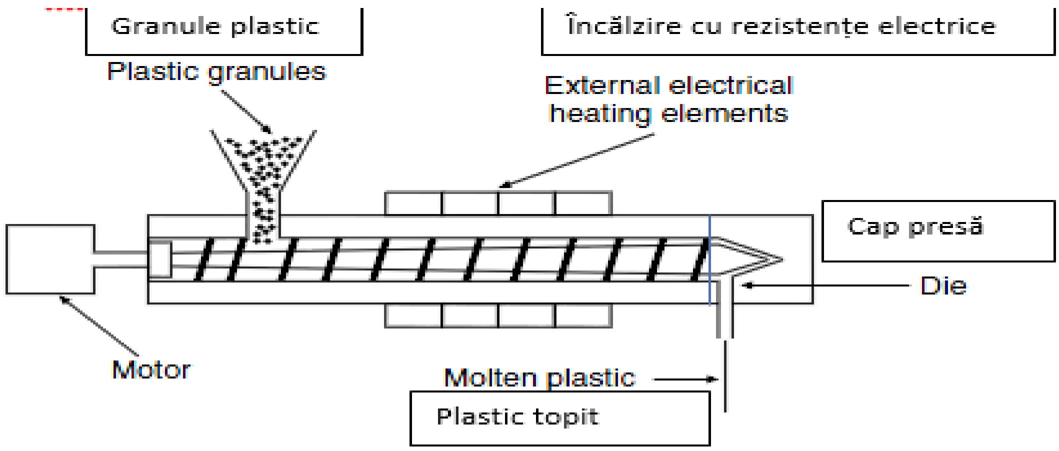


Fig 3: Extruder

Usage: - obtaining sheets, films, plates and tubes.
By extrusion it is possible to make films and foils on the same installation only by changing the diameters. These can be annular - for sheets and films or flat - for sheets, films and plates.

- ***Extrusion of plastic films with flat nozzle for packing (technological line in Annex 1.1)***

Film extrusion:

- are obtained by extrusion with a wide nozzle spinning head;
- the polymer is extruded at as high temperatures as possible to minimize the viscosity of the melt;
- cooling is carried out with air, by direct immersion in water, on cooled inner cylinders or combinations of these variants;
- sheet thickness - up to 0.2 - 0.3 mm (lower limit).

The resulting films may be subjected to the erection operation: they are carried out at the transition temperature to the glass state of the polymer by stretching the polymer with a value of 200-600% of the original size, while also orienting the macromolecules in the drawing direction and increasing the tensile strength; and decreasing elongation to breakage of the foil with its thinning. Two-axis longitudinal and transverse stretching can be increased, increasing resistance in both directions. Increasing resistance is especially important when using food packaging foils.

Etiated foil (also thermo-shrink), when heated, releases internal stresses and shrinks over the packed object into a transparent, waterproof, elastic film.

- ***Plate extrusion (technological line in Annex 1.2)***

It is used to make different thickness plates using different polymers such as PS, PP, PE, etc. Thin plates, up to 0.2 mm thick, are used to obtain food packaging by thermoforming (glasses, containers, plates, margarine trays, yogurt, desserts, etc.). The processing line (see Appendix 1), similar to that of the sheets, also has a calender system (polishing rollers for smoothing plastic tiles), transport and guide rollers, cutting equipment.

- ***Plate co-extrusion (Annex 1.3)***

By using a suitable number of extrusions to feed different plastics, by means of a combining device or a feeding unit, to a common nozzle, multilayer structures of different materials with different properties can be formed. This is called co-extrusion.

Co-extrusion is the simultaneous extrusion of multiple layers of material (from two or more extruders) through the same strip. A) Minimum thickness 30 - 120 µm. B) One and the same extruder can deposit one or two layers of polymer. C) Each extruder must ensure a laminar flow of the polymer melt to avoid mixing the layers. Multilayer films or sheets with 2-9 layers can be obtained. Polymers: PET, HDPE, LDPE, PS, etc.

- **Coating and extrusion lamination (technological line 1.4)**

Extrusion and lamination are used to:

- protect against moisture;
- barrier to water vapor, oxygen, aroma, etc.;
- grease resistance;
- hot sealing;

• attraction for sale, e.g. making glossy surfaces.

For the same purpose, other technologies are also used: Hot rolled lamination (lamination is achieved by passing cardboard and film through a set of Teflon-coated heated rolls at the correct speed and temperature. This makes the film attached to the top and / or bottom of the cardboard). Adhesive lamination (continuous passage of two films / films, one of which is coated with high speed adhesive among several rolls. The processes are distinguished from the type of adhesive used and the way it is applied).

The use of extrusion and laminate cardboard offers remarkable promotional benefits in terms of the visual appeal of consumers. Coating and extrusion lamination adds a thin layer of plastic over the cardboard which can provide resistance to grease and moisture and, where appropriate, heat resistance. Plastic coatings can be hot-sealed. Depending on the application, the cardboard could be covered by one or two sides extrusion. The aluminum layer provides the packaging with a barrier to light, moisture, grease and gas. Aluminum foil is often covered with plastic to ensure product safety and heat sealing. The amount of plastic melt delivered by extrusion is mainly influenced by the flow and temperature of the plastic melt. The most commonly used polymers are PE, PP, PET, metallized polyester film.

The carton wrapped on a roll passes in front of a low-temperature corona discharge surface pre-treatment device to secure the printing inks, coatings and adhesives, then it is covered with molten polymer, PE, PP or PET, with a controlled quantity and temperature. Immediately the coated surface is pressed onto the surface of a cooled steel roller. A roll of film or film is located immediately after the plastic coating extruder. The film or film is fed from the roll to the groove between the molten plastic film and the cooling roll so that the plastic performs the function of a foil / film adhesive on the cardboard, thereby controlling the plastic surface finish. Reverse covers have an NSO (non-Set-Off) finish and print layers usually have a glossy finish.

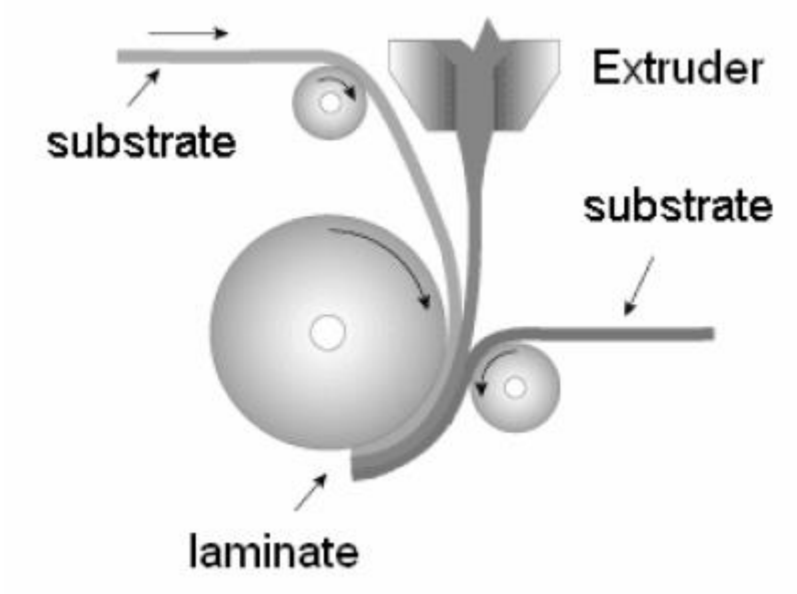


Fig.4 Extrusion coating and lamination, according to [7]

In the end, the coated cardboard is wrapped on the large cores of steel (drums) in batches between 1 and 3 tonnes depending on the product. Each drum has a unique identification code[8]. See annex 1.4.

- ***Sheets and blown films extrusion (technological line annex 1.5)***

In general, the films are, by definition, smaller than 200 µm thickness (1 micron = 1×10^{-6} m). The film is used to wrap tightly the packaging (unique packages, groups of packages, cargoes on pallets), to make envelopes and bags and in combination with other plastics or other materials through lamination, forming also the packaging.

The sheets and blown films extrusion is a simple , economical and productive process. It is the most used method. Through it high quality sheets and films are achieved. In principle, the method consists in a thin-walled tube obtaining (from a few microns to tenths of a millimeter) which is dilated with the aid of an air overpressure. The sheets diameter is from a few centimeters to over 20 meters. It is applicable to polymers HDPE, LDPE, PP, MDPE (medium density polyethylene: 0.926 – 0.940 g / cm^3). To the foil dilation is also obtained her cross stretching and to pull on the winding roll is obtained a longitudinal stretching. The blown films co – extrusion of two polymers (annex 1.6), for example polyethylene - polyamide, polyethylene – polystyrene.

- ***Cave bodies extrusion-blowing***

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[7] Rory Wolf, A technology decision – Adhesive lamination or Extrusion Coating/Lamination
[8] după IGGESUND PAPERBOARD, Reference Manual, Extrusion coating and lamination

It is used for the cylinders manufacturer (bottles, vials) and other cave bodies types (empty inside).

The used polymers: polyolefins (PE, PP), plasticized PVC, PET, PS, ABS, Nylon (PA), etc.

By extrusion a tube is formed into a corresponding mold to the cav made body. Inside the tube compressed air blows and the polymer tube in a visco-plastic state is dilated up to the mold walls in contact with which it cools.

Steps:

- the extruder is continuosly debited a semi-finished product in a tube form;
- the tube is inserted between the molds jaws which define the outer contour of the desired product;
- the mold is closed, the end of the cut tube being closed at the same time. See annex 1.6;
- the insufflation air is usually filtered with sterilized filters. To remove the post-sterilisation of the resulted packaging, the process 'bottle-pack' is sometimes used using the material temperature of 150-230°C to which the cylinder from mold is practically sterile, being realized the food bottling almost simultaneously with the formation. The cold bottled liquids due to a short cooling time.

8.3.2 Thermoforming

The thermoforming procedures involve the termoplaste sheets soaking to heat, followed by vacuum, pressure or a motion plunger application forming. The foil can be stretched on a mould and it takes the piercer form (positive forming) or it can take the cave mold form (negative forming). At the contact with the mold, heat is lost and the material is cooled becoming rigid. The thermoformed products shapes are usually simple (boxes, food trays, different containers). Thermoforming competes with blow moulding and injection moulding. The main advantages of this process are the relatively low cost of thermoforming, the lower cost of the molds and the ease to form large areas with thin parts. Disadvantages: the limited forms, the uneven thickness. The inside foil is fed from a coil and heated before forming or in the mold, then the foil is formed in the mold by various methods.

The thus formed cavity is filled with food, respectively in the open or vacuum atmosphere, after which, the upper foil is used to close it, which is tight welded of the inner foil due to the heat and pressure.

Are used devices for cross cutting for the finished products separation. The products labelling follow and their discharge.

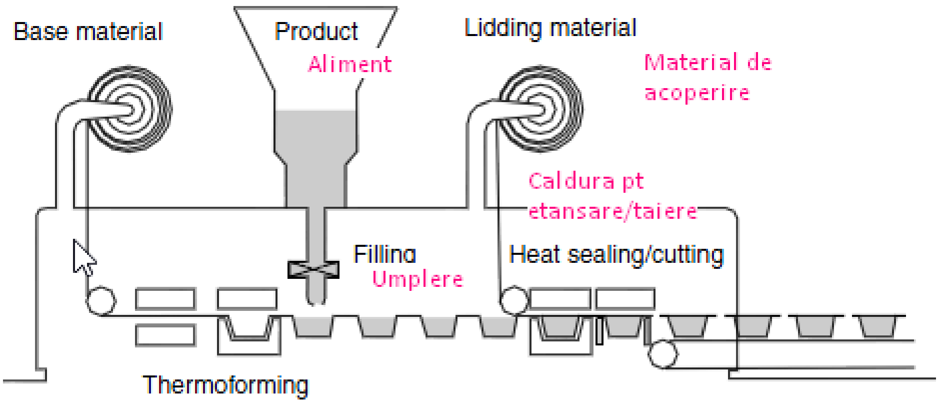


***Fig. 4. Thermoforming, filling, closing line*[9]**

8.3.3 Injection moulding

The principle of the method: is the injection of the melted polymer into a cold mold at a high pressure.

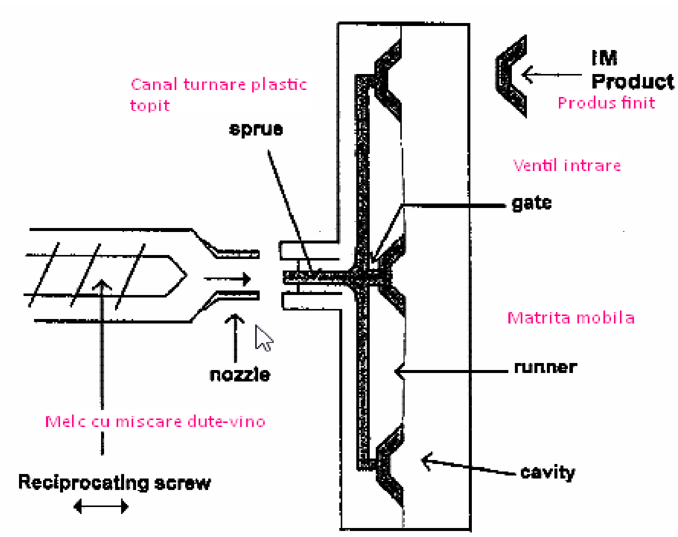


***Fig. 5 Scheme of the injection moulding process*[10] .** See also the annex 1.7.

[9] RICHARD COLES, DEREK MCDOWELL, MARK J. KIRWAN FOOD PACKAGING TECHNOLOGY, Blackwell Publishing Ltd, 2003

[10] *Vlachopoulos and Strutt* Polymer processing, Materials Science and Technology September 2003

The injection moulding process steps are:

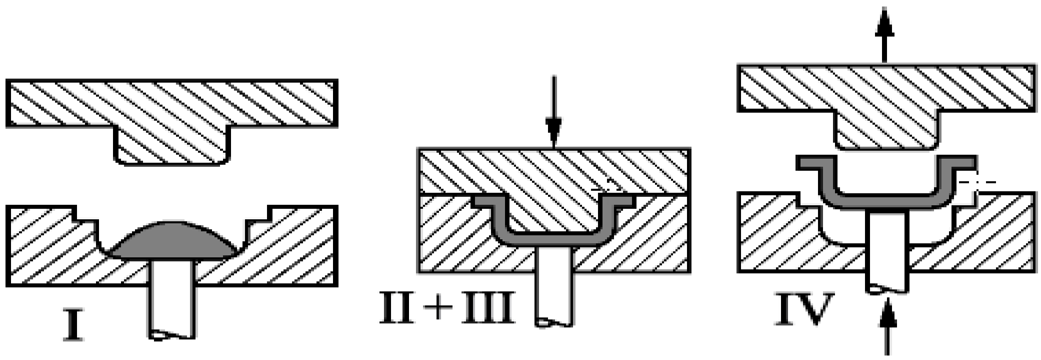
- The cylinder supply with plastic granules to which the snail moves with reciprocating motion;
- The material heating up to melting due to the outer heating and inner friction of the cylinder;
- The snail moves back and the melted plastic passes in front of it;
- The snail moves forward and injects the melted material into the cold mold;
- The material cools and rapidly solidifies to the high pressure created by snail and the unisens input valve;
- The mold opens and the products are ejected by a pitcher.

Advantages: High productivity due to the large number of mold nests and high forming speed, good precision of the formed products, minimal losses through scrap , the objects with complex shape and various sizes can get. The injection line can be fully automated. There is the possibility of obtaining cave bodies (PET bottles) by injection blow molding. The main disadvantage is the high price of the mold.

8.3.4 The compression moulding

The principle of the method: the melted polymer is pressed into the mold.
The compression stages:

I. The supply of the opened mold with the polymer (granules, pills, powder, preformed semi-finished product). The polymer can be preheated to shortening the forming cycle.
II. The polymer closure and heating (uniform in the whole mass) until the melting temperature and the pressing with the aid of the upper part of it (usually hydraulically actuated).
III. The uniform cooling of the formed object by pressing until the indicated temperature for removal.
IV. The workpiece ejecting from the mold with the aid of a pitcher.



Advantages: the possibility to obtain large dimensions objects with low polymer loss, the minimizing of internal stress and parts deformation, accuracy and excellent dimensional stability, low and reproducible shrinkage, good surface finishing of the realized objects, high productivity of modern processes that combines the compression moulding with injection or extrusion.

Disadvantages: is not indicated for fragile objects or complex shapes, the cavity depth is limited to 2-3 times of its diameter, the quantity of introduced material into the mold should be strictly controlled[11].

8.4 The Design of plastic packaging for recycling

In support of the design process of plastic food packaging, in annex 2 are characterized other polymers intended for food packaging and are not included in section 8.1, a table A2.1 is also given, with the physical properties of the main polymers used in plastic packaging, a table A2.3 with use indications of polymers for food packaging, also, a table A2.2 with use indications of polymers for the rigid plastics and a spider diagram fig A2.1, with the use properties of polymers for food packaging. In annex 3 are given a few excerpts on the parts design intended to be molded from plastic.

The properly design in terms of the final structure of the packaging material and production techniques means that the assembly of:- substrates choice - the choice of other raw materials, - the laminates composition, - printing and other processes - the production technique choice, - the application of good manufacturing practices will have as a result a suitable packaging material. The printing can be made on the primary packaging containing a functional barrier that reduces the migration of components from any layer on the non-food side of the barrier, in foods, to "acceptable" levels (the specific migration limit SML or the migration level without concern)[12].

8.4.1 Some concepts of ecodesign

A few concepts of ecodesign:

a) To use compatible plastics. Appendix 2, fig A2.2 presents indications about the compatibility of the basic packaging materials with its components.

b) To use materials of different densities. See fig.1.

c) To cover with labels max. 2/3 of the packaging surface. In automatic installations an optical system of separation classifies the plastics packaging. If 67% or more of packaging is covered, it will be classified on the basis of the label material. If the packaging design does not allow you to follow this suggestion, then:

– Use a label made of the same material as the packaging.
– Use a label with a different density than the packaging.

[11] http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf
[12] EUPIA, Information leaflet Printing Inks for Food Packaging

d) The black and the very dark color interfere with the automatic classification of packaging and absorb the emitted light from the separation optical system. The uncoloured or opaque packaging after recycling have more apps than the colored ones. Some additives used to close in color the packaging can prevent the cylinders or strips production of recycled PET.

e) The inks components used to the packaging colour or their printing can contaminate the recycled material, that's why the printing inks have to use which are not contained in the exclusion list of EUPIA (European Printing Ink Association).

f) The non-soluble adhesives can infect recycled materials with contaminants and they will not be eliminated in the washing process component of recycling, so it is advisable to use soluble in hot water adhesives or the high temperature soluble in alkalis.

g) The silicone can adhere to the recycled material that is why, if possible, should give up its use.

8.4.2 The plastics permeability

For the design, a few notions on the plastics permeability are given. Under equilibrium conditions the permeability coefficient of the non-porous plastic is given by the relationship:

P=D x S (Crank, 1975)

P – the permeability coefficient of the material;

D – the diffusion coefficient, which measures how fast an unwanted component pass through the polymer;

S – the solubility coefficient of the food which shows how much of the unwanted component is in packaged food.

After transformations, without giving details regarding the formulas demonstration, the following expression is reached:

$$P = \frac{QL}{At\,(p1 - p2)} \quad \textbf{(1)}$$

In the SI system $P = \frac{\text{The amount of unwantedcompound } x \text{ wall thickness}}{\text{area } x \text{ exposure time } x \text{ difference of partial pressures of the component}} = cm^3 x\ cm/cm^2 x\ s\ xPa$

In which:

Q – The quantity of unwanted compound – cm^3;
L – The pack wall thickness of polymer - cm
A – The polymer surface through which the unwanted component can pass – cm^2;
t – The exposure time – seconds;
p1 – p2 – The partial pressures difference of the unwanted component located in the pack outside and that of the same compound found in the pack inside. According to Dalton's law: a gas pressure is equal to the sum of the components gases pressures[13].

For air- the air composition expressed by volume percentage, (r) of the components is the following:

Oxigen (O_2): 20,93 %

Nitrogen (N_2): 78,10 %

Argon (Ar): 0,9325 %

Carbon dioxide (CO_2): 0,01 %

Hydrogen (H_2): 0,0018 %

Neon (Ne): 0,0005 %

Krypton (Kr): 0,0001 %

Xenon (Xe): 0,00000 %

Neglecting the rest of the components without O_2 and N_2, Dalton's law for air can be written, as:

$$\boldsymbol{p_{air=}p_{O2} + p_{N2}} \quad \textbf{(2)}$$

The partial pressures of each component gas of air are calculated with the relations:

$$\boldsymbol{r_{o2}x\, p_{air} = p_{o2}} \quad \textbf{(3)}$$
$$\boldsymbol{r_{N2}x\, p_{air} = p_{N2}}$$

For air at atmospheric pressure (p_{air}=1 bar in absolute scale), the partial pressures of the two gaseous components are:

$$\boldsymbol{p_{o2} = 0,21 \times 1 = 0,21\, bar = 21000\, Pa} \quad \textbf{(4)}$$

[13] Food Processing: Principles and Applications, Second Edition. Edited by Stephanie Clark, Stephanie Jung, and Buddhi Lamsal, © 2014, cap 11.Joongmin Shin and Susan E.M. Selke, Food Packaging

$$p_{N2} = 0,79 \times 1 = 0,79\ bar = 79000\ Pa \quad (5)$$

$$p_{aer} = p_{O2} + p_{N2} = 0,21+0,79 = 1\ bar = 100000\ Pa$$[14]

Example: A food packaged in a jar from PET with a thickness of 0.1 cc and a surface area of 400 cm^3 becomes rancid if it absorbs 3 cm^3 of O_2. The permeability coefficient (P) of O_2 is **$1,2x10^{15}$** $cm^3 x\ cm/cm^2 x\ s\ xPa$. The partial pressure of O_2 inside the jar is =0. Which is the lifetime of this product (i.e., the length of time it rages) ?

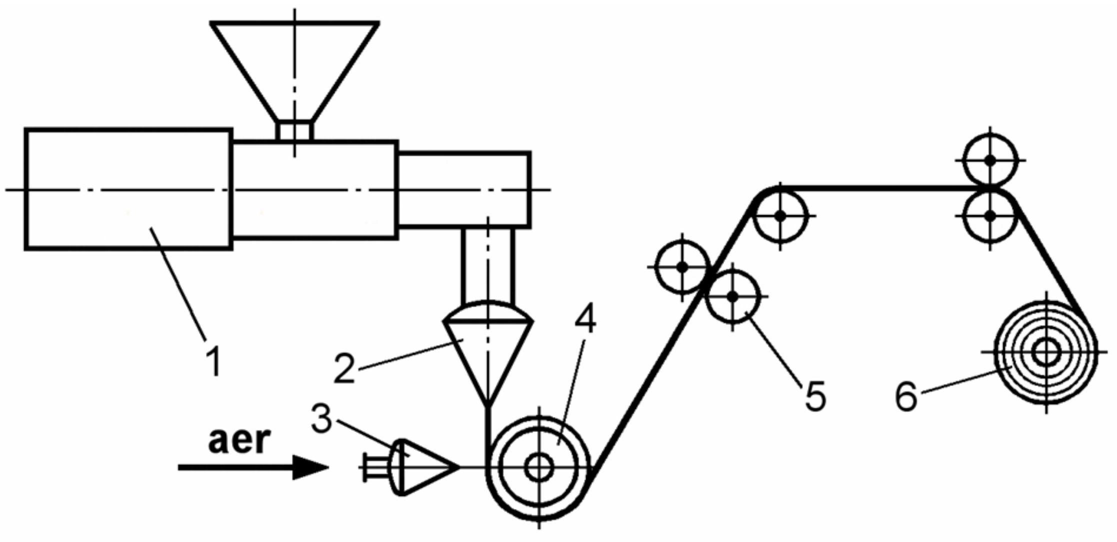
From (1) we obtain: $t = Q \times L / AP(pext - pint)$ where:

$t = 3 \times 0,1/400 \times 1,2 \times 10^{-15} \times (21000-0)$ = 29761904 seconds/24x3600=344 days

In annex A2.4 are data regarding the permeability coefficients of the main polymers. Attention, in annex 2, P is expressed in $cm^3xcm/cm^2xsxcmHg$, where **1 cmHG=1332,22 Pa**, so, for ex. the partial pressure of oxygen **p_{02} = 21000 Pa= 21000/1332,22 = 15,76 cmHG.**

[14] https://ro.wikipedia.org/wiki/Legea_lui_Dalton

1.1 The sheets extrusion through flat filler



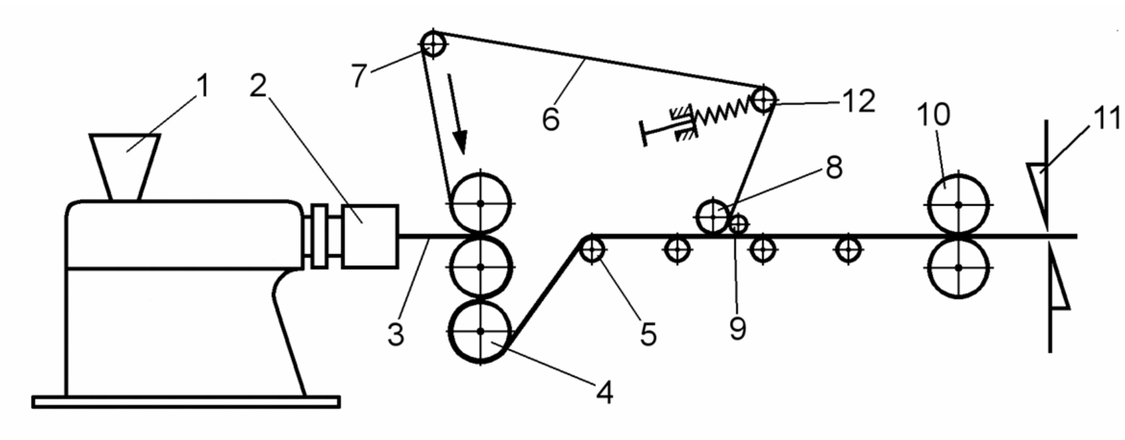
Annex 1. 1 Scheme of the wide slotted slot for plastic foils, after http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf

1. Extruder, 2. Spinning head with wide nozzle, 3. Air cooling system, 4. Cooling drum, 5. Smoothing rolls, 6. Wrapping drum.

The melt of the polymer which is extruded as a membrane, from the extrusion head through the spinning head with wide nozzle is dimensionally stable, it is in contact with several smoothing rolls before being drawn and wound onto the drum. The chrome surface of the first drum is very polished so that the obtained sheet is very glossy and of high clarity. In the extrusion with wide slot (in particular at high working speeds), there's a relatively high orientation of the film in the machine direction (i.e. in the direction of the extruded stream) and one very low in the transverse direction.

The biaxially oriented film can be produced through an extrusion with wide slot, using a stretching device. For example, the polystyrene is first extruded through a wide nozzle head spinning at about 190 ° C and cooled to about 120 ° C by passing between rolls.The moving sheet reheat at 130 ° C, is drawn in both longitudinal and transverse directions of some rods that exert an imposed tension. The stretching rate is from 3:1 to 4:1 in both directions.

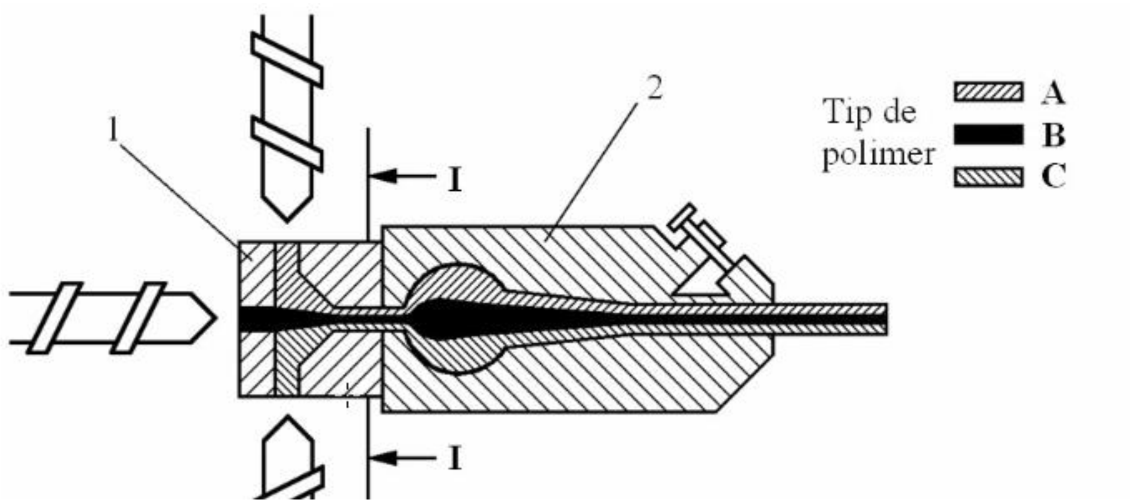
1.2 The thin plates extrusion



Annex 1.2 The scheme of the thin - walled plate extrusion system after.

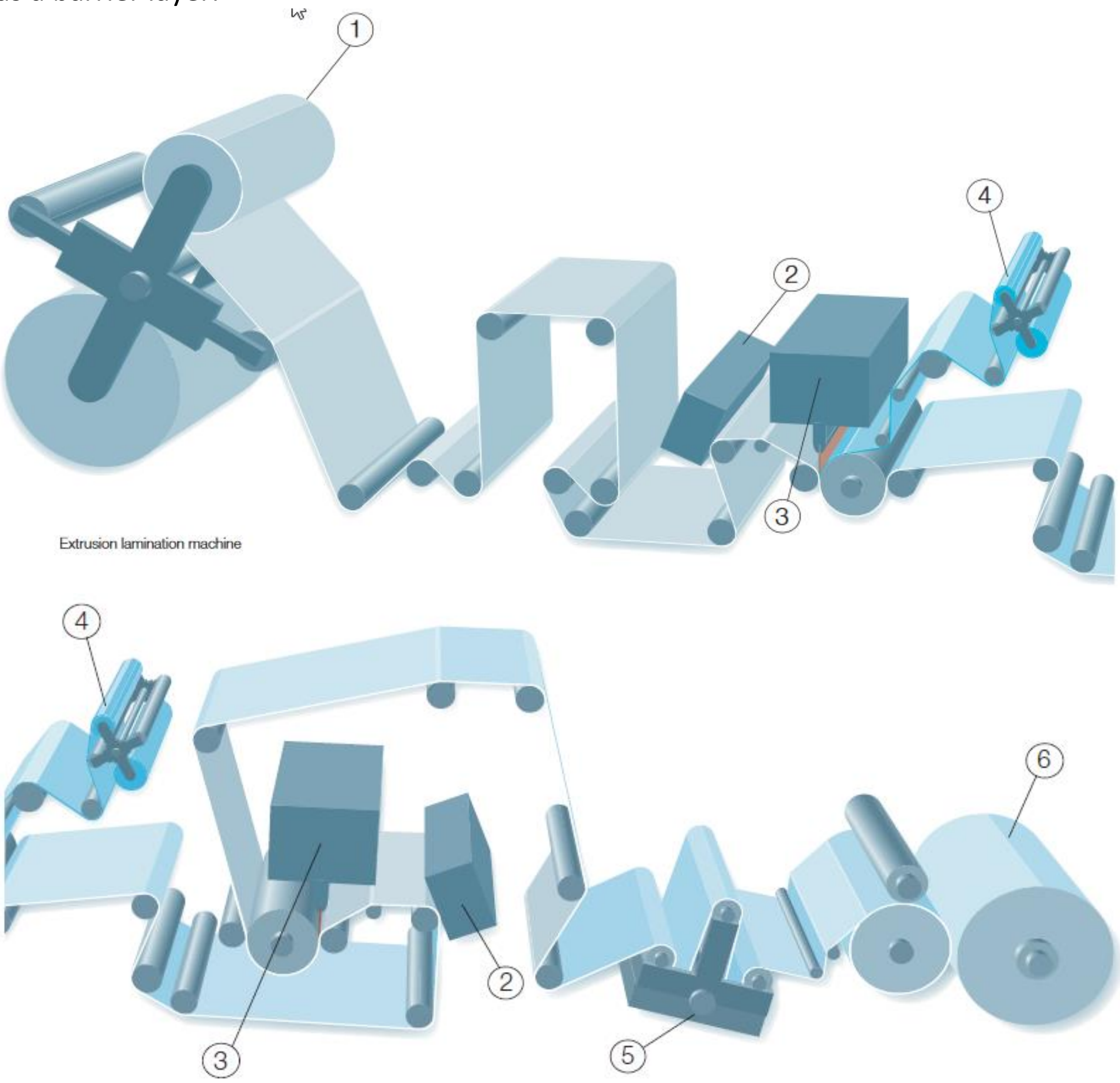
1. Extruder, 2. Wide nozzle spinning head, 3. Extruded plate, 4. The rolls system (calender), 5. Conveyor with rolls, 6. Continuous strip of woven glass fiber, 7,8,9,12 leading rolls, 10. Rubberized shooting drums, 11. Cutting system

Co-extrusion of thin plates



Annex 1.3 The 3 polymers co - extrusion.
1. Supply block, 2. Extrusion head.

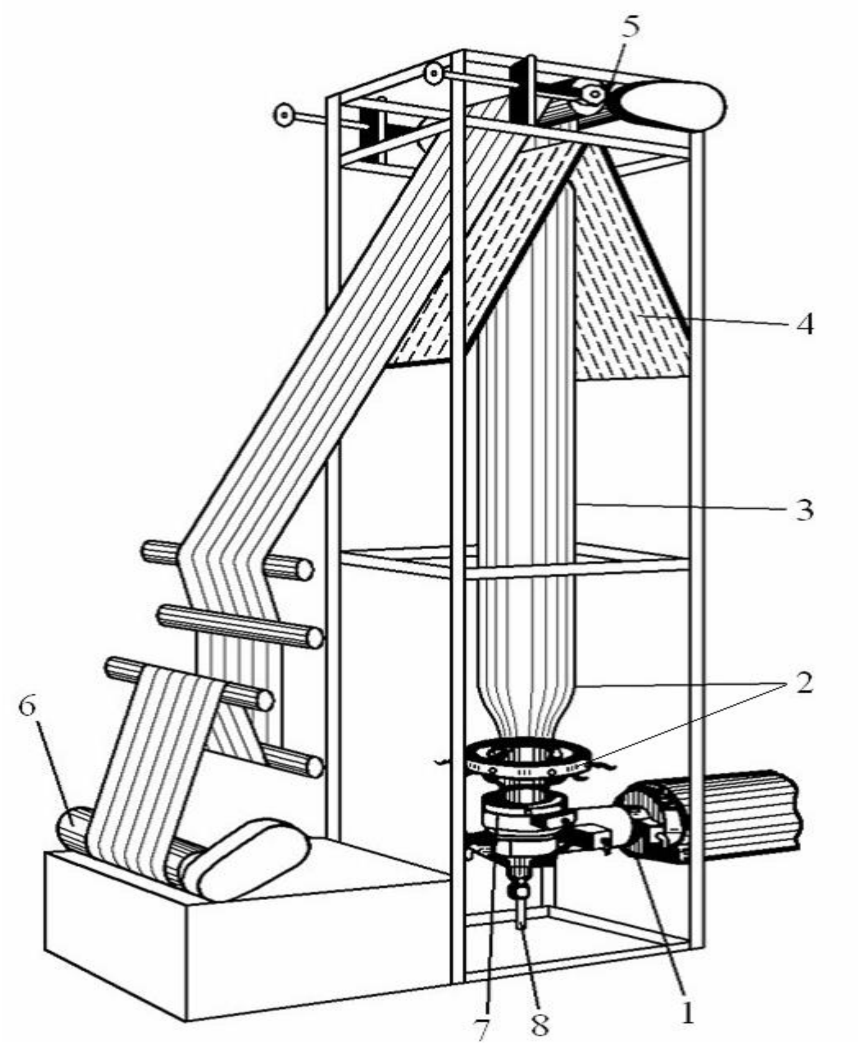
A thin plate of 30 to 120 µm is obtained, of three polymers, the first used as a contact layer with the food, the second is used as a compatibility layer, the third is used as a barrier layer.



Annex 1.4 Extrusion coating and lamination

1. Cardboard, 2. Corona electrical discharge pre-treatment on the print side, 3. The coating with melted plastic from Extruder, 4. Roll with laminated film or sheet, 5. Corona electrical discharge treatment to improve the seal characteristics, 6. Final winding drum.

After IGGESUND PAPERBOARD, Reference Manual, Extrusion coating and lamination



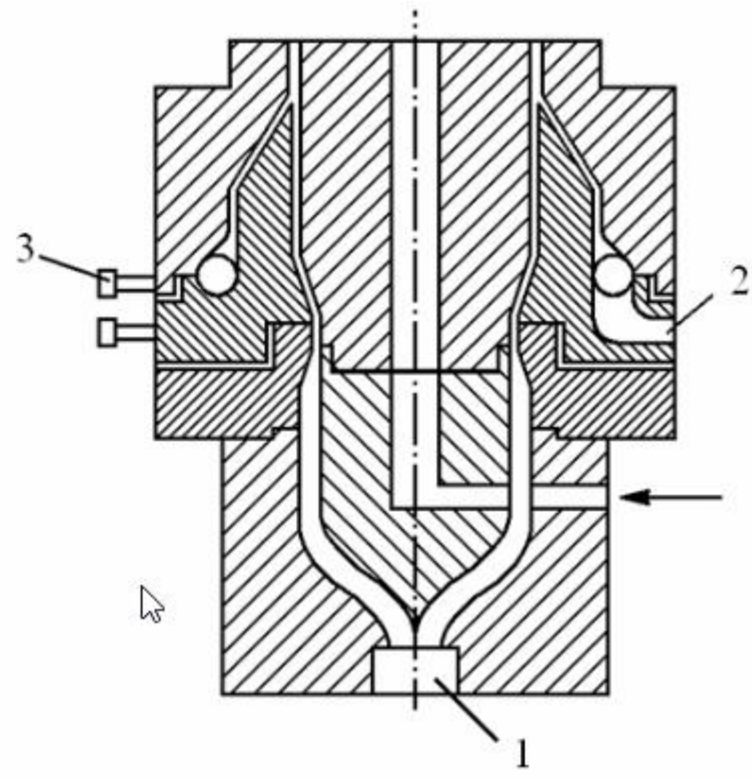
Annex 1.5 Line for the film and foil extrusion with the blew tube on the vertical, after [http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf.](http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf)

1. Extruder, 2. Cooling zone, 3. Blew film, 4. Guide panels, 5. Closing cylinders of the film, 6. Winding device 7. Cooling ring, 8. The air entry for the film dilation.

Features:

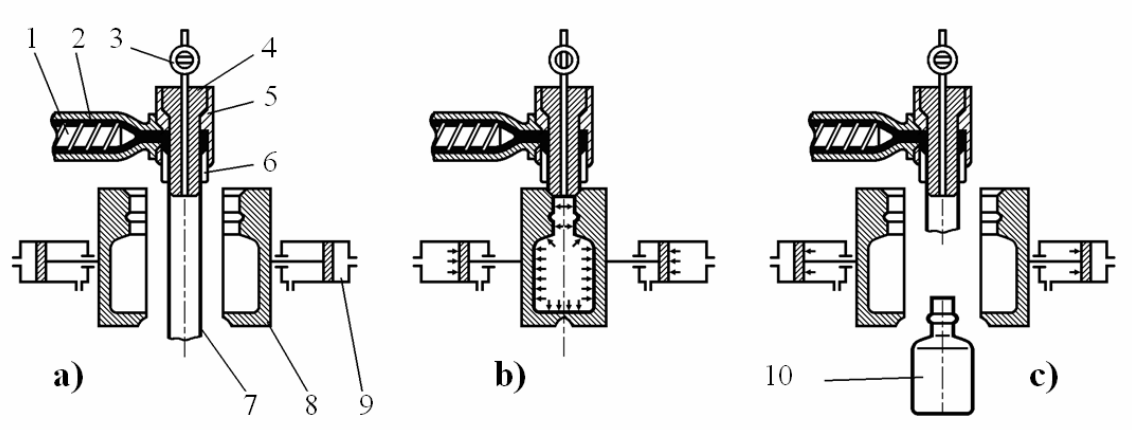
- the gas pressure leads to diameter increasing and transverse drawing;
- the plant productivity is limited by the cooling possibilities of the blew tube;
- the blowing ratio, the ratio of the blew tube diameter and the extrusion slot = 2:1 – 3:1 (usually);
- the longitudinal stretching is provided by the shooting and flattening roles made of steel and covered with fluffy rubber;
- to get uniform properties on the both axes, it is necessary that the longitudinal stretching = cross stretching.

Blown film co-extrusion



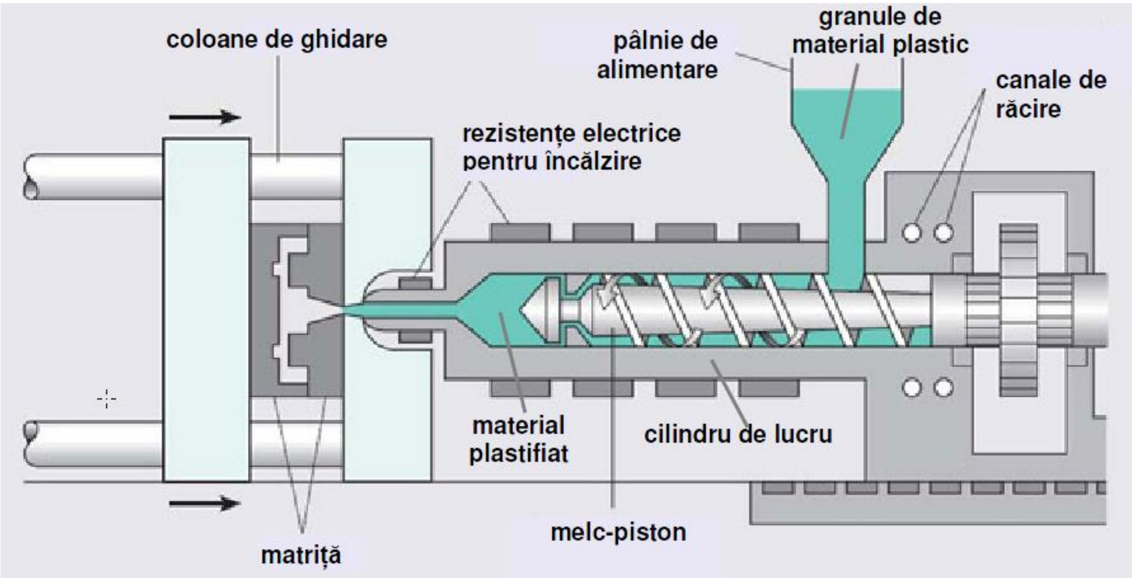
Annex 1.6 Extrusion head to get a bilayer blown sheet.
http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf.

1. The introduction of the inner layer polymer, 2. The introduction of the outer layer polymer, 3. Adjustment



Annex 1.7 The technological process of obtaining of cave bodies by extrusion-blowing. After http://www.tsocm.pub.ro/educatie/cepa/Ambalaje%20-%20CEPA%20-%20Curs%206.pdf.

1. Extruder, 2. Melted polymer, 3. Electromagnetic valve for compressed air admission, 4. Mandrel, 5. Extrusion head, 6. Branch, 7. Semi-finished plastic tube, 8. Half-mold, 9. Half-mold drive cylinders, 10. Finished product.



Annex. 1.8 The formation through injection, after:
http://magnum.engineering.upm.ro/~gabriela.strnad/Tehnologia%20materialelor%20II%20-%20curs%20licenta%20an%20II/2%20CURS/capitolul%207.pdf

A2. Other plastics used in food packaging (see also the 8.1 point)

– Ionomers –The best-known ionomer is Surlyn (Du Pont), it is related to PE, it is transparent, harder and more resistant than PE and very resistant to oils and fats and it has excellent sealing properties. It is used to meat and cheese packaging.

– Ethylene vinyl acetate (EVA) – Is similar to PE and is used in mixture with PE. In general, when increases the percentage of VA, the sealing temperature decreases and the strength increases, the flexibility at low temperatures increases, the fatigue resistance and flexibility increase. It is also an important component in the resistant adhesive to the high temperature used in the packing technique.

– Polyamides (PA, nylon) - PA can be mixed with PE, PET, EVA and EVOH. It can be molded by blowing to make bottles and jars transparent like glass, they have a low weight and they have good impact resistance. PA film with biaxial orientation has high resistance to heat and excellent resistance to breaking and punching. It has good clarity and it is easily thermally deformed. It provides a good barrier to flavors and smell and it is resistant to oils and fats. It has a high vapor permeability and it is difficult to seal heat. These features can be improved by PVdC coating. Also, by polyethylene lamination or co-extrusion, this structure is used as the thermoformable bottom plate, for bacon and cheese packaging in vacuum or gas packs (MAP/ modified atmosphere packaging). The film can be metalized.

– Polyvinylidene chloride (PVdC). PVdC seals to heat and it is an excellent barrier to water and gas vapours and to fatty and oily products. As a result of high barrier to gas and odor, it is used to protect sensitive foods to flavor and smell, because of the flavor loss and for the volatile contaminants penetration. It is used in flexible packaging as a monomer, by co-extrusion or as coating material, which can be applied using solutions in organic solvents or aqueous dispersions on plastic films such as BOPP and PET and paper and cardboard. PVdC is a widely used component in meat and cheese packaging, snack foods, tea, coffee and confectionery. It is used in hot filling, retorts, storage at low temperatures and MAP, as well as to the ambient temperature filling and for distribution in a wide range of packaging shapes.

– Styrene butadiene (SB) - The SB copolymer is also a packaging polymer- it is resistant and transparent, with a very glossy finish. The blown film has high permeability to water and gases vapours. It is used for fresh products packaging.

– Acrylonitrile butadiene styrene (ABS) - Is a copolymer with different properties depending on the proportion of the three components polymers. It is a durable material with good resistance to impact and stretching and it is flexible. It is translucent or opaque and it is used in the manufacture of large containers.

-Ethylene vinyl alcohol (EVOH) – It is an excellent barrier to O2 and it is resistant to the absorption and penetration by many products such as oils, fats, flavors and odors. It is sensitive to moisture and therefore it is used by co-extrusion in structures with several layers such as films for flexible packaging, sheets for thermoforming and to bottles injection so that he wouldn't come in contact with the liquid.

The PS/EVOH/PS and PS/EVOH/PE structures are used for MAP (Modified Atmosphere Packaging) of fresh meat and pasta, salads, coffee, compote etc. PP/EVOH/PP is a high barrier used for products pasteurization such as fruits, pate, baby food and semi-processed food which can be heated in the microwave oven. Also, it can be laminated by extrusion with many other polymers for various purposes.

– Polymethyl pentene (PMP or TPX) – It is transparent, resistant to temperatures up to 200°C, it has good resistance to chemicals, transparency and gloss. The main use of food packaging is the coating on the cardboard by extrusion for the use in baking applications in the form of cardboard boxes and trays for bread, cakes and other cooked foods in the package. The packaged food can be heated in the microwave oven and in other ovens.

– High nitrile polymers (HNP) – It is used in the manufacture of other plastic such as ABS and SAN giving them barrier properties to gases and tastes and a good chemical resistance. HNP is suitable for food packaging and it is made under the BAREX brand which is blown and cast as film by extrusion or injection. It is transparent, resistant and rigid. Is used by co-extrusion with HDPE for the bottles manufacture and with PE, PP and Aluminium foil for applications in flexible packaging. The plates can be thermoformed.

– Fluoropolymers (PCTFE/PTFE) – PCTFE has the highest barrier properties to water vapors of all polymers and it is resistant to many chemicals at low temperatures. It can replace the aluminum foil and it is available as film or plates. It is transparent, it can be sealed to heat, it can be laminated, thermoformed, metalized and sterilized. It is relatively expensive and although it is possible it is not applied to food packaging. PTFE (Teflon) has a high melting temperature and it is a inert and waxy polymer. It is used in the construction of packing machines.

– Cellulose-based materials – The regenerated cellulose film (RCF) is made from extracted cellulose from wood dissolved and regenerated by extrusion through a slot, cast on a drum and treated with acid after that it is wound on a drum in the form of film. RCF, called Cellophane is a renowned material. It is not a thermoplastic material, it is a polymer with high molecular weight, naturally obtained. To make it flexible, it is plasticised with humectants of glycol type. The flexibility degree can be changed from rigid to very flexible, it can be folded or used by twisting. It is a weak barrier to water vapors and this property is used with products that have to lose moisture, such as bakery products and other flour confections to achieve the right texture when it is packed. (Plastic films, for example. PP or PE would keep the relative humidity too high inside the package and, therefore, will favour the moulding). When it is dry, RCF is a good barrier to oxygen. The welding/ sealing to heat and the barrier improving to water and gas vapors may be obtained by coating with nitrocellulose or PVdC. It can be coloured (red for Christmas gifts) and metallized and it is printable. The cellulose acetate is also derived from cellulose. It is very transparent and glossy. It can be printed. It was used by lamination on the cardboard and windows to the cardboards design. It is more expensive compared to BOPP which has similar properties, it has also been replaced by other polymers like PVC, PET,PP, PVA.

– Polyvinyl acetate (PVA) – It is a polymer that forms an amorphous material with good adhesive properties in terms of accessibility and power of the dried welding. The main use of PVA in the packaging of food is as an adhesive dispersed in water. PVA adhesives are used to seal the side seams of the folding cardboard boxes and packaging of corrugated cardboard and to the lamination on the aluminum foil.

Table A2. 1 The properties of the main polymers used for plastic packaging

Name	Density g/cm^3	Tm Melting °C	Tg glass °C	Tensile strength MPa	Elastic limit %
PET	1.37-1.455	260	75	55-75	50-150
LDPE	0.910 -0.940	98-115	-	8.0 -31	
PVC	1.30-1.58	100260	57-82	50-80	20-40
HDPE	0.952-0.965	130-137	-	18.5-24.8	55
PP	0.855-0.946	160	-	31-41	15
PS	1.04-1.05	240	95	45-60	3-4
ABS	1.04-1.05	-	105-115	29.6	20
SAN	1.06-1.1	-	102-104	32-40	4
PC	1.2-1.22	267	150	55-75	80-150
PA Nylon 6	1.15	254	-	59-90	50

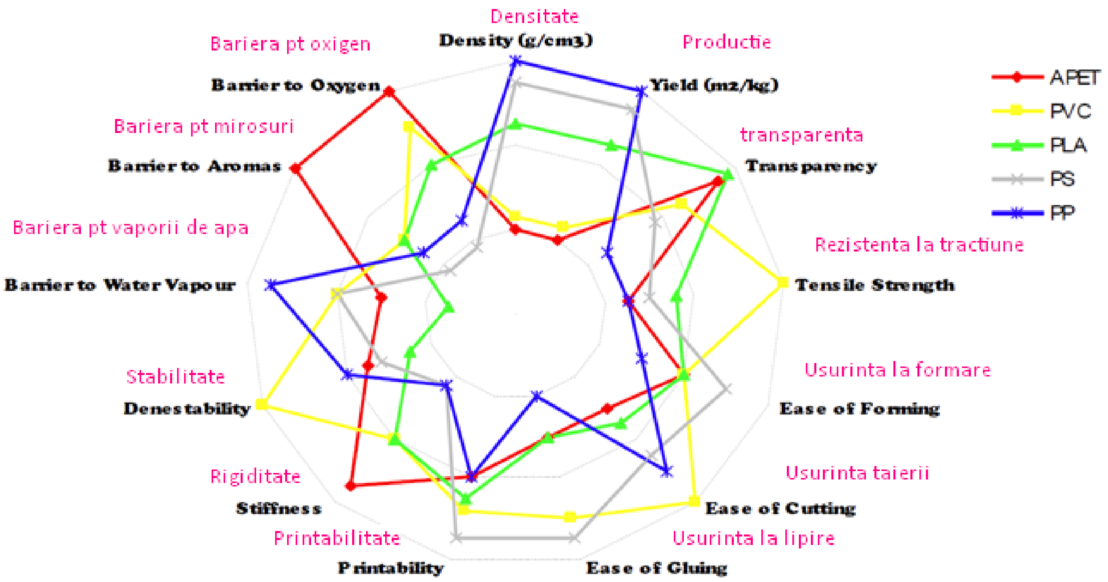


Fig. A2.1 The spider diagram of the properties of polymers use, after Design for plastic packaging recyclability, Mepex Consult AS 2017

Table A2.2 Table for the plastics use in stiff food packaging after[15]

Plastic	LDPE	HDPE	PP	PVC	PET	PS
Food approval	Yes	Yes	Yes	Yes	Yes	Yes
Approximate hot fill temperature	80	95	120	50 to 65 Depending on type	60 standard, 85 partial heat-set, 95+ full heat-set	60 to 95 depending on type
Oxygen barrier	Very poor	Poor	Poor	Moderate to good	Good	Poor
Moisture barrier	Good	Excellent	Excellent	Moderate	Moderate	Poor
Impact strength	Excellent	Good	Poor to good depending on grade	Poor to good depending on grade	Excellent	Poor to moderate depending on grade
Clarity	Moderate	Poor	Poor to good depending on grade	Good	Excellent	Poor to excellent depending on grade
Main applications	Soft caps	Bottles, caps and closures	Pots and tubs, screw caps, hinged caps, some bottles	Bottles/sticle	Carbonated beverage and other bottles	Yoghurt and cheese pots
Moulding processes	Injection moulding, extrusion, blow moulding	Injection moulding, extrusion, blow moulding	Injection moulding, extrusion, blow moulding, termoforming	Extrusion, blow moulding, thermoforming	Stretch-blow moulding, thermoforming	Injection moulding, thermoforming

[15] F. Hannay, Nampak Group Research & Development, Rigid Plastics Packaging - Materials, Processes and Applications, Rapra Technology Limited, UK

Table A2.3 The use properties of the plastic materials used as food packaging[16]

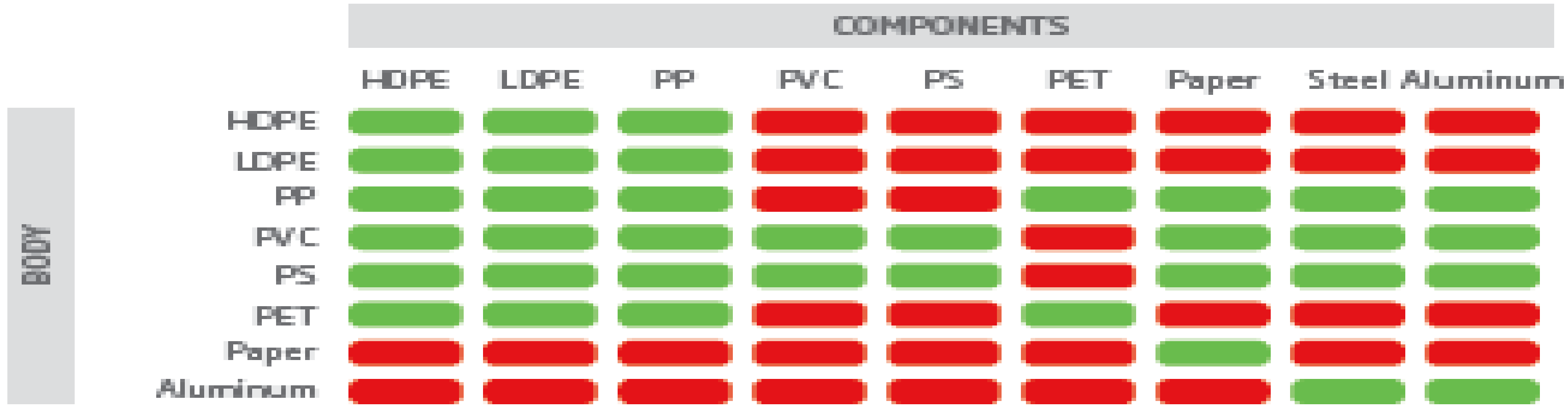
Material	Product characteristics		Marketing issues		Environmental issues		
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Cost**
Polyolefins PP,PE	Good moisture barrier; Strong; Resistance to chemicals	Poor gas barrier	Lightweight	Slight haze or translucency	Recyclable; High-energy source for incineration	Easily recycled in semirigid form; more difficult identification and separation for films	Low cost
Polyester	Strong; Resistance to hot filling; Good barrier properties		High clarity; Shatter resistance		Recyclable (a),(b)	Easily recycled in rigid form, but more difficult identification and separation for films	Cheap, but with higher cost among plastics
Polyvinyl chloride PVC	Moldable; Resistance to chemicals		High clarity		Recyclable (a)	It contains chlorine; It requires the separation from other waste	Cheap

[16] After: KENNETH MARSH & BETTY BUGUSU, Food packaging and its environmental impact, www.ift.org

Polyvinylidene chloride PVDC	High barrier to moisture and gases; Heat sealable; Withstands to hot filling;		It maintains product quality		Recyclable (a)	It contains chlorine; It requires separating from other waste	Cheap, but higher cost among plastics
Polystyrene PS	Available as rigid, film and foamed form	Poor barrier properties	Good clarity		Recyclable (a)	It requires separation from other waste	Cheap
Polyamide PA	Strong; Good barrier properties				Recyclable (a)	It requires separation from other waste	Cheap, but higher cost among plastics
Ethylene vinyl alcohol EVOH	High barrier properties to oils and fat	Low barrier properties to moisture; sensitive to moisture	It maintains product quality to oxygen-sensitive products		Recyclable (a)	It requires separation from other waste	Cheap when it is used as film
Polylactic acid PLA	Biodegradable; Hydrolyzable				Recyclable (a),(c)	It requires separation from other waste	Relatively expensive
a) All thermoplastics are technically recyclable and they are recycled for the environment protection and they contribute to lowering the cost price.							
b) They are extensively recycled for the production of non-food product.							
c) The macromolecules (polymers) can be broken down to monomer level and reprocessed.							

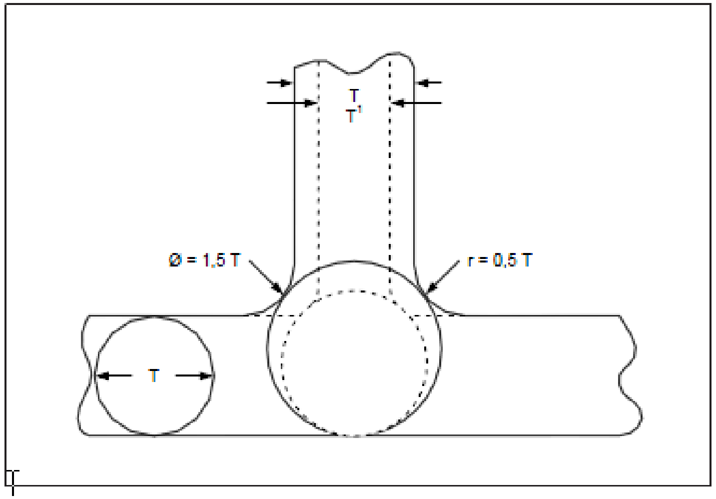
Table A2.2 Compatible materials

Table A2.4 The permeability of the main polymers after http://www.faybutler.com/pdf_files/HowHoseMaterialsAffectGas3.pdf

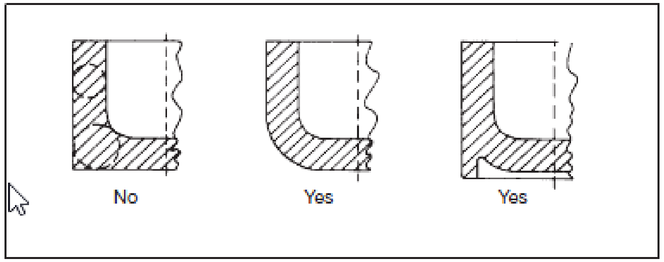


Polymer	Common/Trade Name	Permeability Coeffcients at 25∞C (P × 10^{10}) Oxygen	Moisture
Poly(isoprene)	Natural Rubber	23.3	2290
Poly(chloroprene)	Neoprene G	4.0	910
Poly(isobutene-coisonrene)	Butyl Rubber	1.3	110
Poly(vinyl chloride)	PVC (unplasticized)	0.045	275
Poly(tetrafluoroethylene)	Teflon	4.2	4.8
Poly(tetrafluoroethylene-co)	Teflone FEP	4.9	17
Poly(ethylene), low density (0.914 g/cm^3)	LDPE	2.2	68
Poly(ethylene), high density (0.964 g/cm^3)	HDPE	0.3	9
Poly(propylene) density (0.907 g/cm^3)	PP	1.2	35
Poly(vinyledene chloride)	Saran	0.005	0.5
Poly(trifluoro chloroethylene)	Kel-F81	0.04	0.1
Poly(ethyl methacrylate)	Plexiglas	1.2	3200
Poly(carbonate)	Lexan	1.4	1400
Poly(ethylene terephthalate)	PET	0.035	130

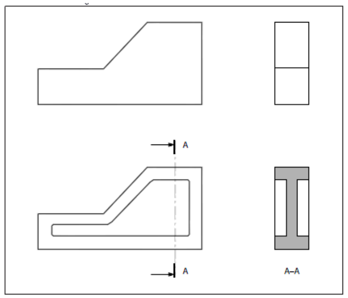
Permeability Coefficient P = (amount of permeate) (film thickness)/(surface area) (time) (pressure-drop across film).
Units of P: [cm^3 cm]/[cm^2 s (cm Hg)].



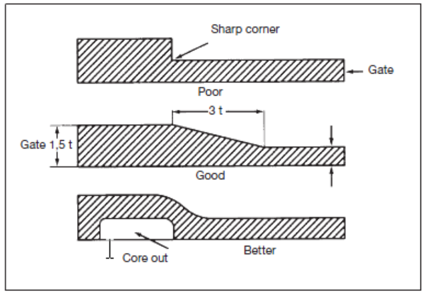
A3.1 Rib dimensions



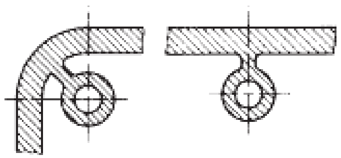
A3.2 Outside corner design



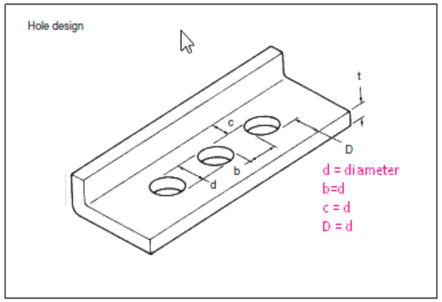
A3.3 Uniform design for wall



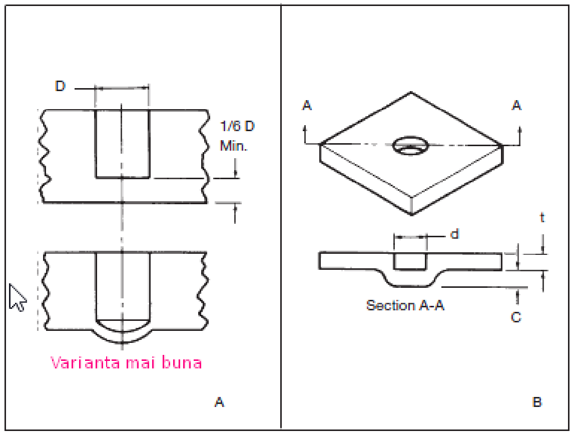
A3.4 Transition to different thickness



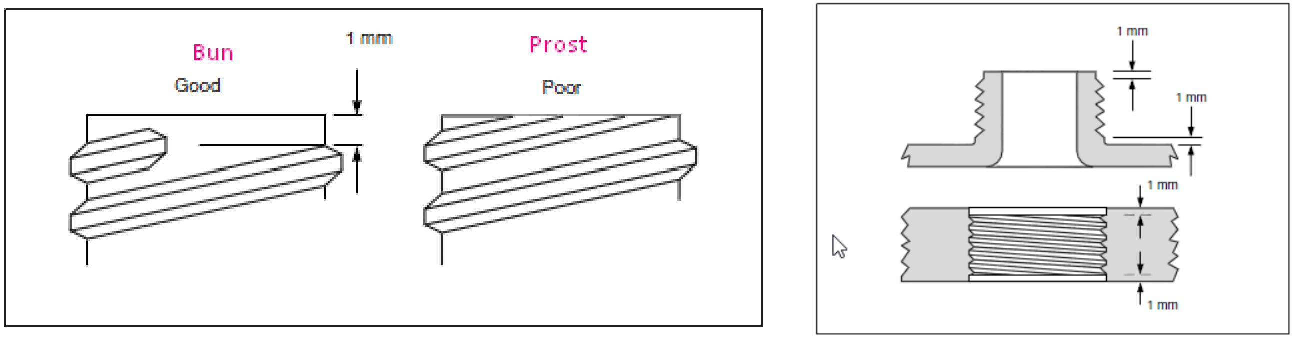
A3.5 Good design for bosses



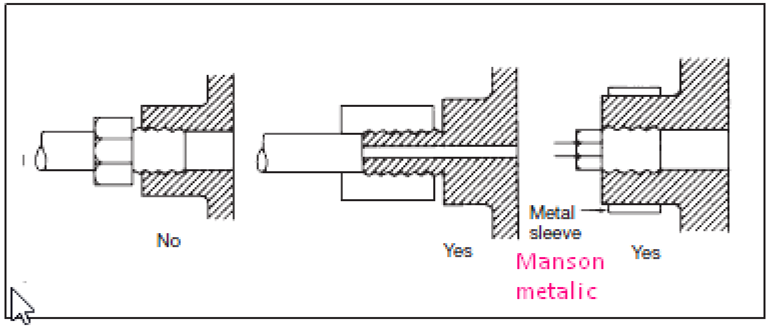
A3.6 Holes design thickness



A3.7 Unsteaded holes



A3.8 Correct threads termination



A3.9 Threaded metal-plastic threads

Tolerances: In general by the pouring into the mold, can be achieved equal tolerances with:

$\Delta to = \pm (0,1 ....0,0015*a)$ [mm]

where a is the size in [mm].