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PLASTICS IN PACKAGING
(Plastics Technologies for low cost Packaging Application to Developing Countries)

by

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This study gives a general account of plastics processing and application in selected fields of packaging with special consideration of food packaging. It has been prepared by two specialized institutes in Austria, the Laboratory for Plastics Technology (LKT-TGM) and the Laboratory for the Packaging of Foodstuffs and Beverages (VLG). Corresponding to special competence, part I was prepared by VLG (A. Wawruschka), part II by LKT-TGM (H. Hubeny).

Vienna, December 1989
H. Hubeny
A. Wawruschka

Plastics in Packaging
(Plastic Technologies for low cost Packaging Application to Developing Countries)

Part I
Packaging Application

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1.Techno-Economic Requirements of Food Packaging

Preface (1) (3)

Packaging is an indispensable aid for the transportation of goods in perfect condition from the producer to the consumer. Technical, economic, legal, consumer-related, and ecological requirements are to be met at the lowest possible material consumption and economic costs (conservation of resources and reasonable costs). The demands define packaging of goods as a task of optimization.

The combination of different demands from very different sectors like

- material production
- packaging process
- transport
- warehousing
- trade
- consumer and
- municipal waste management

results in an interdisciplinary setting of tasks for packaging engineering. The listing of the most important factors to be considered in food packaging in figure 1.1. shows that the task of packaging engineering extends to the creation of systems which ensure

- perfect handling of the (usually automated) packaging process
- compliance with logistic functions
- re-use, utilization or disposal of used packages without creating problems.

Packaging engineering is in truth system engineering.

Packaging is not just indispensable in the distribution of agricultural products to the consumer; properly designed it prevents spoilage of many food commodities between harvesting and consumption. This is an effective means of waging war on waste and an important factor in agricultural development.

Special attention is paid to packaging needs a , possibilities in developing countries, suggesting materials and methods of direct value to them. Nevertheless, no clear distinction can be drawn between developing and developed countries as far as packaging is concerned, since there are developing countries whose progress in packaging techniques is very advanced, while there are industrialized countries whose standard in the field of packaging lags behind remarkably.

Vital factors in the promotion of packaging are: initial costs of installation and machine running; the output to be obtained with standard packaging machines; limitations imposed; development in progress and future trends; selection of systems designed to achieve maximum output with minimum outlay while maintaining the required standard of quality .

1.1.Introduction (1)

In most developing countries food is bought in daily rations; packaging plays therefore only a secondary part. It is nevertheless important for the storage of food between consecutive harvests, for making available industrially produced food that is richer in nutrients from a physiological standpoint, for all supplies from distant countries (such as animal protein), and, quite generally, for the distribution and export of agricultural products. The importance of packaging on the economy of a country depends therefore principally on the status of the food industry, on the existence of a stockpiling economy, and on the export volume.

Points of decisive importance to packaging are: available raw materials, the manufacturing processes in use, and the manner of distribution to the consumer. Selecting a packaging material is a complex task. A certain product may be frozen and either wrapped or bagged, canned, packed unfrozen into film bags or glass jars, dried, or even freeze-dried. In highly industrialized countries decisions about product preparation and packaging follow two major principals: costs and maximum acceptability in the market; du-

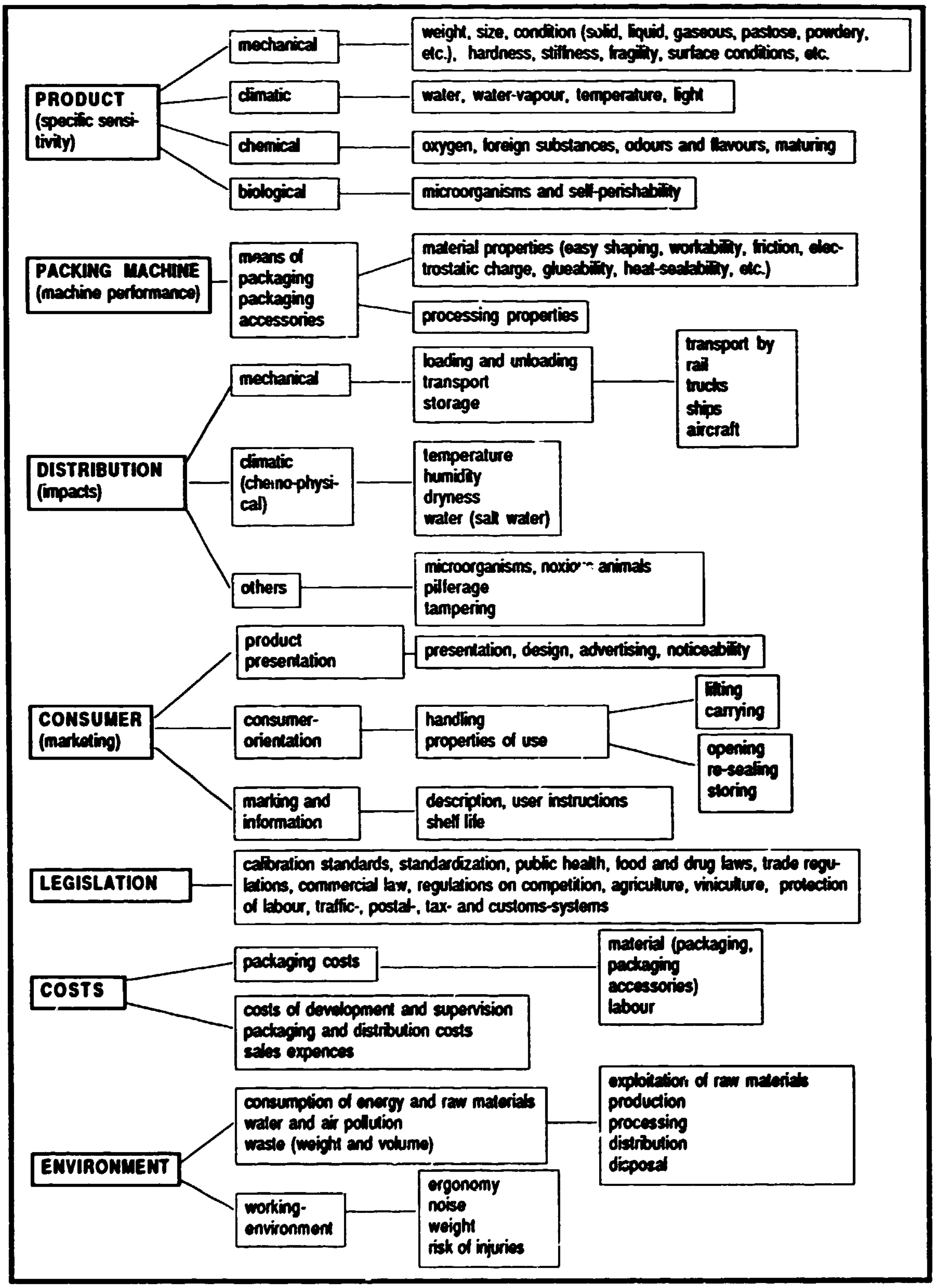

Figure 1.1. Factors to be considered in food packaging (3)

ring the last few years health and environmental requirements have also become important factors. In less developed economies other factors must be taken into consideration: availability of materials, special storage-life requirements, and extreme conditions in distribution.

1.2.General product-related requirements (1) (2)

1.2.1.Introduction

Packaging should not be more costly than it is necessary for the intended purpose.

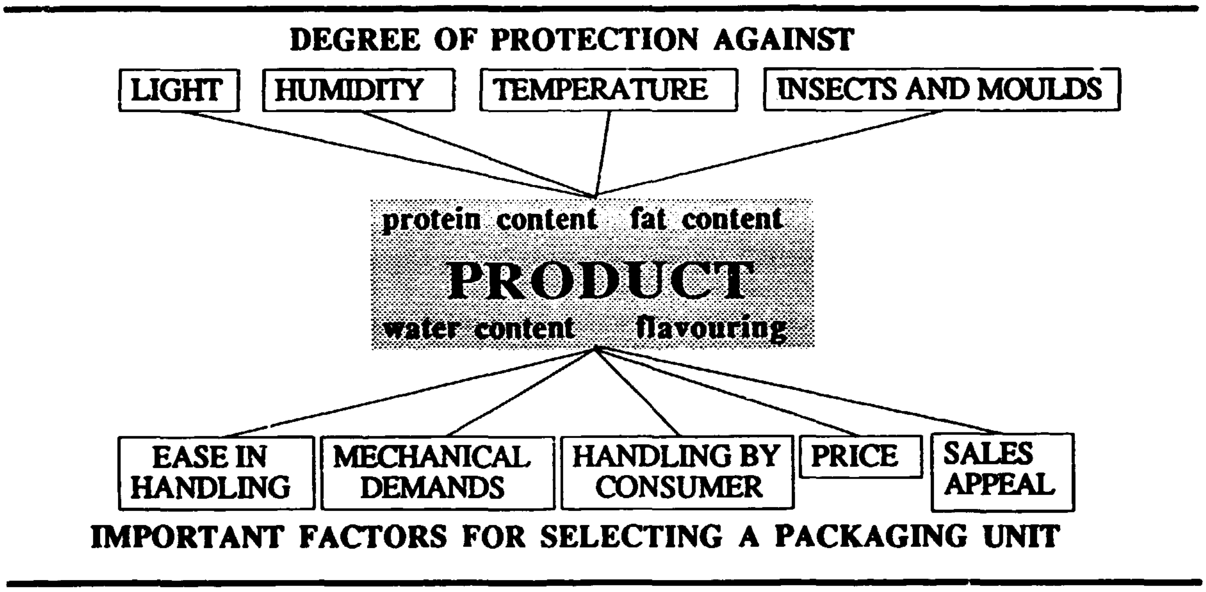

Fig. 1.2: Important factors for selecting a packaging unit (1)

- The most important function of packaging is to ensure the consumer's supply with food of the same high quality as in fresh food or in freshly prepared food. It must be known what mechanical and climatic conditions a product will be subjected to, and also how much time will go by between production and consumption.
- The packaging material has to be compatible with the packaged product, ensuring that it does not impart any odours or flavours to the product and that no substances soluble in the product have any toxicologic effects.
- Packages must be easy to fill and close quickly and safely. The packed product has to be easily distributed and stored. The size of the package should be convenient for handling and consumption. Opening and re-closing the package should be easy.
- A packed product has to sell itself in self-service markets. The consumer expects not only integrity of product and package, but anticipates also factual information concerning the product, such as content, storage conditions and time, possible uses etc. on the package.

Fig. 1.2. shows the main factors influencing a packaging concepts and the most important factors causing product-spoilage.
In most cases these kinds of spoilage may be greatly inhibited by suitable packaging. Not so temperature-induced (encymatic or microbial) spoilage, which can be the most important one of these factors. For example: If the storage time of a particular fruit is 4 days at 20 °C it may be 12 days at 2 °C. There are, however, limitations because some varieties of fruit are damaged by exposure to low temperatures (e.g. bananas turn black when exposed to temperatures below 10 °C).

1.2.2.Products tending to microbiological deterioration

The species of microorganisms causing spoilage of fresh food depends on climatic conditions and is greatly influenced by pH value and moisture content of the food. The growth rate of microorganisms responsible for spoilage depends primarily on storage temperature, on the relative humidity , and the composition of storage atmosphere, especially on its carbon dioxide concentration. Lowering storage temperature not only prolongs the latent phase of the growth curve but also lowers the inclination of the logarithmic growth phase. Similar results to those with low temperatures are achieved by storage in carbon dioxide atmosphere. In this case one must watch out for such side effects as off-colouring. The usefulness of carbon dioxide increases with decreasing temperature.

Various species of microorganisms can grow only if equilibrium relative humidity does not decrease below a certain value. It may therefore be concluded that whenever biological spoilage plays the decisive role, keeping quality can be increased by preferably lowering storage temperature. If the storage temperature cannot be lowered below a certain limit then there is no other option but to shorten the time between production and consumption.

Chemical preservation is another way to increase the shelf life of perishable products. In this case microbial spoilage is inhibited by bacterial substances, but there are also undesirable effects to human health. Therefore chemical preservation should be restricted to cases where there is no other alternative.

Deep freezing, if properly done, leads to total inhibition of microbiological spoilage if storage temperature is sufficiently low. Since deep freezing does not definitively destroy microorganisms and encyme systems, care must be taken that the food is consumed as soon as possible once the freezing chain is interrupted.

Sterilization by heat, if properly done, also causes total inhibition of all biological changes. After opening a sterilized container, the contents are exposed to reinfection and should therefore be consumed as soon as possible.

Dehydration, if properly done, causes total inhibition of all biological changes once a sufficiently low moisture content has been attained and maintained during storage. All dehydrated products are hygroscopic and must be consumed more or less quickly after opening the container, depending to their moisture sensitivity.

The main objective of all preservation methods is therefore the inhibition of microbiological spoilage. This does not prevent abiotic staleness. Abiotic spoilage, however, usually proceeds at a much slower rate and can therefore be detected at an earlier stage, so that its progress may be stopped. No general rule can be given as to whether staleness proceeds faster in dehydrated products or in sterilized non-dehydrated products, since it depends more or less on previous processing and the specific sensitivity of the product. A hard and fast rule is that products more sensitive to encymatic changes should be sterilized, whereas products inclined to non-encymatic browning and hydrolytic destruction should preferably be dehydrated to a low moisture content or deep-frozen.

It often happens that changes of a different nature occur simultaneously. For every product to be marketed one must discover the change that will play the limiting role at the proposed temperature. All preventive measures have to be oriented on this dominant change.

1.2.3.Moisture sensitive products

The relation between relative humidity and moisture content of a product which is in equilibrium at the actual temperature is called the sorption isotherm for water vapour. The hygroscopicity of foodstuffs varies in a wide range and must not exceed a safety limit during the product's turnover time if it is to be protected from any noticeable change in quality. The ambient relative humidity will, in general, be much greater than the equilibrium relative humidity over the dehydrated product in a package. This will cause a humidity gradient from the exterior of the package to its interior. The permissible turnover time can be determined if the amount of moisture permeating the package under normal conditions, the filling weight, the initial and the permissible final moisture content, and the mean humidity gradient from the exterior to the interior of the package are known. If the calculated shelf life period turns out to be too short, a packaging material with lower water-vapour permeability must be chosen.

The safety limits of dehydrated food as observed in actual practice are in a small scale dependent on turnover time and storage temperature. Even though almost all products are liable to deterioration from all causes of quality change, such as composition, prior processing, and ambient atmosphere, it may be said that moisture content and temperature determine to a high degree which of the changes is the limiting one to the product. In general, the imperishability of dehydrated food, except that of fatty products with very low moisture contents, increases with decreasing moisture content.

1.2.4.Oxygen-sensitive products

Oxygen absorption may be seen similar to water vapour absorption. However the amount of absorbed oxygen is much lower. A considerable part of available oxygen is absorbed physically and can be removed by applying a very low vacuum.

Physical absorption is followed by chemical absorption, which may cause the formation of objectionable flavours and odours. Oxidative changes, especially oxidative fat spoilage, are accelerated by light rays.

Since many foods are more sensitive to oxygen than to moisture, it is advisable to recommend the storage of oxygen-sensitive food in an atmosphere with low oxygen content and the use of packages that are highly impermeable to oxygen. Oxygen constitutes the limiting factor for the storage of many dehydrated foods like coffee, mashed potatoes, dehydrated meat, sliced dry sausages, bacon, sliced hard cheese, dehydrated carrots, freeze-dried vegetables, and freeze-dried chickens.

To slow down auto-oxidative changes the partial pressure of oxygen can be reduced by evacuation or packaging under inert gases like N_2 or Co_2. Another possibility is to increase moisture content. Increasing moisture content, however, may induce browning reactions. Therefore the moisture content should not be raised to a degree where these reactions become predominant.

1.2.5.Light-sensitive products

Light energy may cause changes in flavour, colour and loss of vitamines of light-sensitive products.The energy content of light rays is inversely proportional to the wavelength. Ultraviolet rays are usually more dangerous than the visual wavelength-range.

Simplifying the complex relations between incident light, light transmission, and reflection of the packaging material and light absorption of the packed product, one may say that the bigger part of incident light energy which is not reflected or absorbed by the packaging material will be absorbed by the product.

Depending on the colour of the package, different parts of the spectrum are absorbed. Reduction of oxygen contents helps also to lower the destructive effect of light rays. Light-proof packages should be used for highly light sensitive products such as dairy products, cured meat, mayonnaise, beer, dehydrated tomato puree, and biscuits.

1.2.6.Products of high fragrance and flavour sensitive products

Food is - with very few exceptions (e.g. spices) - much more sensitive to contamination with off-odours from adjacently stored smelly products than to any loss of aroma.

For protection against any undesireable loss of aroma, relatively efficient aroma proof films can be used, whereas any migration of strong odours (especially into fatty food) requires a hermetic package made of tin-plate, glass, aluminium foil or multilayer combinations with the required properties.

1.3.Specific product-related requirements (1)(3)(4)(5)

1.3.1.Fruit and vegetables

1.3.1.1.Basic requirements for the packaging of fruit and vegetables

The choice of packaging for fruit and vegetables depends on the degree of respiratory activity of the product, which is, for example, strong in the case of leafy vegetables (which tend to dry out and wrinkle) and berries, but rather low in tubers (which are dormant) and root vegetables (which are also almost indifferent to loss of moisture). Packaging of fruit or vegetables can increase keeping quality only slightly or not at all and has predominantly hygienic purposes. For quickly perishable fruit and vegetables in packages it is much more important to maintain a suitable low temperature. One must bear in mind that certain tropical fruit suffer low temperature breakdown even at temperatures above freezing point. The period between harvest and cold storage must be as short as possible for all sensitive varieties.

The required water vapour transmission rate of the package depends on the variety; perforated polyethylene or shrink packages (on trays) with open ends are frequently used, since oxygen and carbon dioxide permeability are required. Packages should be transparent to allow visability of content. Wet strength is required for washed vegetables and soft fruit.

To protect goods from mechanical damages, transport packages and containers must be lined in a manner that prevents goods from being tainted when stacked (boxes made of polyolefins, foamed polystyrene trays). Bulk height and number of layers depend on the product to be packaged. Specially formed inserts made of foamed or unfoamed PS, PVC, etc. are recommended for very sensitive goods. Air circulation should not be obstructed.

The size of retail packages should improve shelf utilization, allow a more effective presentation, ease the transfer from shop to home, and should - above all - be a measure of hygiene. The most suitable packaging materials are transparent with sufficient gas- and water vapour permeability. More impermeable packaging materials have to be suitably perforated.

Trays made of rigid PVC and PS (also foamed) are recommended for very delicate goods. Perforated trays or small baskets are preferable for berries because they avoid an accumulation of liquids. Sufficiently perforated bags made of PE or nets or sacks made of plastic fibres are used for heavy nominal contents.

Trays of foamed PS which are wrapped with shrinkable films are very often used.

1.3.1.2.Bananas

The proper marketing of bananas depends on controlled artificial ripening in central ripening rooms. Mixed ripeness is the greatest problem in the transport of bananas. To avoid this it is important that conditions of transport should approximate optimum storage conditions for unripe fruit, which are a temperature of 13 °C and sufficient ventilation to prevent any accumulation of ethylene in the storage environment. Bananas are usually packed as hands or fingers in cartons or wooden boxes. Fibreboard boxes have certain technical and economic advantages.

1.3.1.3.Citrus

Citrus fruits are transported successfully even over long distances at temperatures between 4.5 and 7,2 °C.

The most common containers have about 29 dm^3 capacity, holding a net weight of just about 20 kilogramms. Mesh and perforated PE-bags are widely used as consumer packages.

1.3.1.4.Pineapples

For long distance transport pineapples are packed in wooden cases with wood wool as protective material. A transit period of approximately 2 weeks at 10 °C is about the maximum for pineapples, provided the fruit is picked at the right stage of ripening. Care must be taken to prevent the developement of water blisters (cerestomella paradoxa).

1.3.1.5.Papaws (Papya)

Papaws are very difficult to be exported because of their susceptability to storage and transit rots and because there are many different strains. Strains with greater resistance to disease are usually of inferior flavour. Rapid ripening at high temperature and humidity in ripening rooms represses mould growth.

1.3.1.6.Mangos

Mangos are generally picked in a hard, green condition and will subsequently ripen with good flavour. Anthracnose is a problem in some countries but good control of this disease has been obtained by hot water treatment applied after harvest. Optimum storage temperature is about 13 °C and storage life is 2 - 3 weeks depending on variety. Controlled atmosphere and PE bags extend storage life.

1.3.1.7.Avocados

Avocados, too, can be picked in a green, hard condition. Fruit maturity, cultural practices, variety, and climatic conditions during fruit development affect the sensitivity of avocados to low temperatures. At an optimum storage temperature between 7 and 13 °C, you can reach storage life about 4 weeks. Controlled atmosphere and packing in PE bags will increase storage life.

1.3.1.8.Passionfruit

The purple passionfruit is one of the most popular sort of fruit grown in the tropics and sub-tropics. Considerable loss in weight occurs during storage, but this can be prevented by storage in PE bags. Optium storage temperature 5 - 7 °C, storage life 4 - 5 weeks.

1.3.1.9.Litchis

Litchis become unsaleable in 3 days. Stored at 7 °C in perforated PE bags, a storage life of 3 - 4 weeks can be obained.

1.3.1.10.Vegetables

Adequate ventilation of the package is the most important factor in the transport of vegetables in the tropics, and spacers are often necessary in rail transport to provide adequate ventilation for the bags. Washing and prepackaging is becoming more wide-spread in tropical countries and an extension of imperishability using perforated flexible film bags has been obtained.

1.3.1.11.Nuts

Macadamia, cashew, and pecan comprise the majority of nuts grown in tropical and sub-tropical regions. The first two varieties are used almost exclusively for processing purposes. Shelled nuts may be held in certain types of transparent gas-tight laminated plastic bags under vacuum, carbon dioxide, or nitrogen for a maximum of about 3 months at 21 °C. The limiting factor is the gradual diffusion of oxygen through the package and its influence on bruised surface regions. For longer periods the nuts should be kept under refrigeration.

1.3.2.Dairy products

1.3.2.1.Basic requirements for the packaging of dairy products

Packaging for dairy products has to

- be in accordance with the respective food laws, i.e. the use of the packaging materials and packaging accessories which come into contact with the filled product must be allowed for the intended purpose

- be free of flavours and odours (particularly products with little aroma of their own are damaged in quality by even small amounts of foreign aroma)
- have sufficient barrier properties against penetration of foreign aroma substances
- be low in germ content because of easy microbiological spoilage
- guarantee sufficienbt protection against light
- be adequately resistant against foreseeable demands of transport and storage
- be easy to open; it must also be possible to empty the contents completely
- be recloseable if the product is not used fully at once
- have wet strength, water- and product resistance
- have printing which does not rub off and is free of odours.

Moreover, composite packaging materials must not delaminate.

1.3.2.2.Pasteurized milk, coffee cream and whipping cream

Pasteurized milk and cream with different fat content tends to

- spoilage by micro-organisms (which will be increased by interrupted refrigeration)
- absorption of odours and flavours
- formation of light-induced off-flavours in connection with oxidative processes.

Packaging materials and packages should meet the following requirements:

- low bacterial counts (<10 - 50 counts/dm^2)
- closures should be liquid proof and packages should be tight enough to prevent flow-out of the product and contamination with microorganisms
- no inherent flavours and odours and sufficient barrier properties to prevent penetration of odours and flavours
- sufficient light absorption for wave-length up to 550 nm
- sufficient wet strength.

PE-laminated boxes, cups made of PS, PP or PVC or coextruded PE-films (dyed dark on the inside) are suitable for imperishabilities of up to 8 days. Up to one year-imperishabilities in plastic containers are only possible with adequate side-thickness and proper lightproof dye (HDPE- or PP cups).

1.3.2.3.Aseptic packed and sterilized milk or cream with different fat contents

The most important specific sensitivities are

- re-infection (microbial spoilage)
- absorption of foreign odours and flavours
- formation of light-induced off-flavour through the effects of sun-light or artificial light, particularly in connection with oxidative processes.

Packaging must therefore

- be low in germ content
- be suitable for sterilization processes prior to filling or if already filled
- be closeable in germ-tight condition
- be free of odours and flavours
- have sufficient barrier properties against foreign aroma substances
- be light- and oxygen-proof
- have wet strength and
- be liquidproof.

Cups made of PS, PP or PVC are suitable for imperishability of up to 10 weeks. Longer periods of imperishability are achieved by plastic cups made of HDPE or PP with sufficient thickness in connection with lightproof pigmentation or additional packaging and by the use of composite packaging materials.

1.3.2.4.Sour milk products

The most important specific sensitivities of sour milk products are

- spoilage due to micro-organisms (yeasts, moulds)
- post-acidification at temperatures of more than 10 °C
- whey-precipitation and deposits of gel, or
- decomposition of gel whilst whey is extracted (yoghurt)
- absorption of foreign odours
- oxidative changes by light and the influence of oxygen
- formation of carbon dioxide (kefir, sour milk).

Means of packaging have to be water-resistant; they must have sufficient wet strength; packages including closures must be tight. Easy opening should be possible and hygienic protection of the upper cup-edge is needed for drinking cups. One-way packages and their seals have to be as sterile as possible or must be sterilizable prior to filling. Gas drainage for products that form carbon dioxide should be possible.

Yoghurt containers should have sufficient stability in order to keep the yoghurt gel. Impermeability to flavours, protection against light, resistance to ethereal oils, fruit acids, and lactic acid are additional requirements.

Cups and dishes made of PS, PP or PVC (dyed sufficiently light-proof and perhaps also PVDC-laminated) are recommended just as much as prevalent plastic packagings for durabilities of up to 6 weeks as do cups that are formed just prior to filling, laminated paper cups or aluminium-foiled combinations.

These means of packaging plus flanging seals (possibility of gas leakage) are also a common solution for products with strong carbon dioxide formation.

1.3.2.5.Butter

Slight desiccation (development of yellow oil edges), accompanied by a change in taste and appearance, light- and oxygen-induced rancidness is just as much a problem as the adoption of foreign flavours and odours and the tendency to microbiological changes.

Packaging materials must therefore be resistant to fats, have sufficient wet strength, and must be persistent to flavours. Packaging materials with low water vapour permeability like plastic-coated paper or PVC cups are necessary for imperishability of even up to 12 days at 10 ° C. Imperishability of up to 3 weeks at 10 ° C can only be reached with means of packaging that are impermeable to water vapour and light, e.g. aluminium laminated composites or cups with the same properties. Longer imperishability can only be attained at storage temperatures lower than 0 ° C.

1.3.2.6.Fresh cheese

Microbial spoilage, particularly due to yeasts and moulds, precipitation of whey, sensitivity to light as well as absorption of foreign odours and flavours are specific sensibilities of fresh cheese. Packagings should therefore be low in germs, seals should be proof to microorganisms with adequate protection against light (the higher the fat content, the more sensitive); impermeability to flavours and odours, fat resistance and impermeability to fat should be guaranteed. There should be as little headspace as possible; and easy opening should also be feasable (packages for more than 250 g content should also be recloseable)

Cheeses with little dry matter demand stable-formed packages. Cups made of PS or PVC with adequate sidewall-thickness are generally used. Forming prior to filling is advisable for longer imperishability.

1.3.2.7.Semi-hard and hard cheese in portion packs

Major problems are

- Spoilage due to yeasts and moulds
- temperature sensitivity (condensation of fat and further ripening with changes in odour, flavour, and consistency)
- sensitivity to light and oxygen
- desiccation in connection with loss of weight and changes in consistence
- sensitivity against loss of carbon dioxide
- absorption of odours.

Means of packaging should be low in germs (particularly mould spores) as well as fat resistant and greaseproof. Permeability to oxygen, water vapour, carbon dioxide, and also to odours should be low. Packages must have sufficient tear- and puncture strength at cooling temperature and should be hermetically sealable (heat-sealable packaging materials).

Film combinations made of cellophane, PET-P, PA, and polyolefins (particularly LDPE) are used. Lamination with PVDC, gas-tight films for evacuation such as PVDC-shrinkable films or better still CO_2- gas flushing (which suppresses mould-growth) is recommended for longer storage periods.

1.3.2.8.Processed cheese and preparations with different ingredients and spices

Microbial spoilage, desiccation, fat deposits, oxidation, absorption and loss of odour, and the sticking together of slices are the specific sensitivities of processed cheese.

Packagings have to be low in germs and free of mould spores, fat resistant and greaseproof, with low permeability to oxygen and water vapour. Other requirements are corrosion-resistance against emulsifying salts and kitchen salt, rigidity (particularly in case of cheese spreads) and temperature resistance (in case of hot filling at 70 - 80 °C). Means of packaging should not stick to the cheese, and the packages should be easy to open and recloseable.

Plastic tubes, cups, and films (for hot filling), PVC-laminated films made of cellophane, PET-P or PA and polyofins (for packaging under protective gas or vacuum) are used for imperishabilities of up to 3 months. Sufficient protection against light by means of printing, dyeing or additional packaging should be striven for.

1.3.2.9.Unportioned cheese

Basically all prerequisites mentioned above apply, but they are very much subject to sort-specific sensitivities which cannot be dealt with in detail in our context. However, it should be pointed out that cheeses with spreading- or moulding formation tend to develop abnormal flavours in case of insufficient CO_2-permeability which does not take the respiratory activity of ripening cheeses into account. Expansion in volume must be taken into account in case of ripening packaged cheeses. Ripening films must follow the expansion in volume and allow for the gas substitution needed.

Some typical examples of application to illustrate the use of plastics as means of packaging are:

Swiss cheese in block form: Means of packaging that are oxygen- and water vapour proof, fit tightly to the surfaces and follow the expansion in volume, like PVDC or PET-P, which is used in form of evacuable, shrinkable, tightly closed bags or films.

Gouda: Evacuable, shrinkable bags of PVDC are used as coatings.

1.3.2.10.Dried milk

The main sensitivities of dried milk are

- Oxidation by atmospheric oxygen
- light-flavour
- hygroscopicity
- absorption of extraneous odours, and
- microbiological spoilage.

Packageing-properties must therefore meet all those demands; they have to be recloseable in case of larger portions.

These demands are met, for instance, by heat-sealable combinations with aluminium foil, water vapour-tight cardboard boxes with or without inner bags made of PVC-coated paper or PVDC-coated plastic film. N_2- or vacuum packaging in gastight bags or metal containers allows durabilities of up to 3 years.

1.3.3.Meat and poultry

1.3.3.1.Portioned fresh meat

In general fresh meat is not marketable without that bright red colour formed by oxymyglobin under access of atmospheric oxygen. This colouring keeps only for a limited time and is also dependent on temperature. Fresh meat is sensitive to desiccation and oxidation under the influence of light, to absorption of strange flavours and most of all to microbiologic spoilage. A storage temperature of -1 °C is necessary for optimal imperishability.

Films for packaging must have great oxygen permeability, moderate water vapour permeability, grease resistance, and wet strength. The strength must be sufficient for strains caused by cooling temperature. Depending on each packaging procedure, stretchability or shrinkability as well as good heat sealability is required.

Suitable materials are: Soft PVC films (stretchable or shrinkable) and tissue films made of oriented PE (fitted to prevent water vapour), cellophane films, coated on one side only. Portion trays can consist of foamed PS or PS with high impact strength. These packages have above all hygienic purposes and counter any loss of weight.

1.3.3.2.Portioned minced meat

The mincing process makes meat highly liable to biological spoilage. Packaging has to meet the same requirements as in the case of fresh meat. It is therefore recommended to use the above mentioned packaging materials while keeping a storage temperature between -1 and +1 °C (never for longer than 24 hours).

1.3.3.3.Fresh meat in evacuated storage packages

Fresh meat packed in large portions in order to mature or to be a supply of stocks is particularly endangered by microbiological spoilage; maximum hygiene during processing is therefore essential. Evacuation in order to delay spoilage brings about a change in colour, which is, however, to a large extent reversible by access of air.

Storage should take place at a temperature of 0 °C; larger amounts of piling pressure should be avoided, for such pressure favours the secretion of meat juices (this is also the reason why meat is cut along fibrous border lines).

Packaging materials must have very low oxygen- and water vapour permeability. Resistance properties must furthermore meet the conditions of restapling and transport. Gas-tight clipping or sealing must also be possible.

Suitable means of packaging are: Bags made of PVDC films, tubes made of PET-P or PA/PE-combinations, bags made of PA/PE or PET-P/PE combinations, for longer storage periods also PVDC-laminated.

1.3.3.4.Deep-frozen portioned meat

From the market's point of view bright red surface colour is required. Deep-frozen meat must be protected against desiccation (frost blight), absorption of foreign flavours, and the influence of light.

The means of packaging must have adequate strength for the temperatures applied and low permeability to water vapour, light (unless stored in darkness), and oxygen. They must also fit tightly to the products packaged (stretchable or shrinkable, if need be also evacuable).

Economy-sized packs use vacuum bags made of PA/PE or PET-P/PE or shrink bags made of PVDC-laminates or PET-P. For small-size packages, polymer-coated cellophane (for deep-freezing) or polymer-coated aluminium foils are used. Imperishability of up to 5 months can be attained at
- 20 °C, cold resistant foils of low oxygen permeability under vacuum at -30 °C bring up to 9 months, with primarely colour conservation as limiting factor.

1.2.3.5.Deep-frozen minced meat

Basically the same requirements as mentioned above are expected.

Plastic coated aluminium cups, bags made of aluminium-compound foils, and cups or bags made of largely water vapour- and flavour proof heat-sealable plastics with adequate low grease permeability are used.

1.3.3.6.Fresh poultry

Due to easy microbiologic spoilage, both, killing and packaging procedures, must take place with as little as possible initial microbial content. Too much exposure to light is dangerous. Storage should take place at less than 2 °C.

Means of packaging must have low water vapour- and oxygen permeability, adequate strength at 0°C and should be as stretchable or shrink-able (depending on packaging procedure) as possible.

Bags made of shrinkable PVDC and PET-P and of LDPE or netted PE are used. Packaging should fit tightly (shrinking, packaging under tension and/or evacuating) and should have the lowest possible oxygen permeability for storage. Heat-sealable films made of cellophane, PE or PVC, with presentation trays made of PS, suffice for short turn-over periods.

Overwrapping with a bottom fold, with stretch film on top and shrink film at the bottom is often used in fully automatic packaging.

Imperishabilities of up to 2 weeks are possible, if hygienic standards have been maintained during production and if the refrigerating chain (0 °C) has not been interrupted.

1.3.3.7.Deep-frozen poultry

Frost blight (changes in colouring and accelerated fat rancidness), sensitivity to light, and absorption of strange flavours are the main problems in storing deep-frozen poultry.

Packaging materials should be impermeable to water vapour and oxygen, with as little translucence as possible (in case of the hazard of storage in full light). Adequate resistance at -20 °C , and high stretchability or shrinkability should make packaging materials fit closely to the product (to avoid frost blight).

Films made of PVDC and PET-P tubes are the usual means of packaging. A storage temperature of -20 °C allows for imperishabilities of up to 9 months.

1.3.4.Pickled and salted meat products

Oxidation processes that are strongly accelerated by the influence of light and by higher temperatures bring about changes in the colouring of the red pickle colouring matter and to fat oxidation, with the two processes accelerating each other. Desiccation leads also to changes in colouring and in consistency. Low initial bacterial content has to be maintained, particularly in case of cooked and cut pickled products.

Packaging occurs usually under vacuum or inert gas (lowest possible oxygen content is especially required in case of access of light) in oxygen-proof (and therefore also adequately water vapour-proof) films. Films with lower impermeabilities can be used in case of shorter turnover times and sufficient light protection (additional packaging, aluminium composites, printing). The means of packaging must furthermore be fat resistant and grease-proof, must show good heat sealability and have to be strong enough to endure the manipulations customary to wrapping.

Products less sensitive to oxygen (different kinds of sausages) are not usually packed under vacuum (predominantly hygienic protection), and sometimes a process of desiccation should be achieved by using water vapour permeable films.

Film combinations made of cellophane, PET-P or PA with polyolefins (particularly LDPE) as well as non-transparent combinations (PP/PA/PE, PET-P/PA/PE) are suitable for vacuum- and inert gas packaging. Depending on use, flat bags or deep drawn containers with lid-films are applicable. Troughs may consist of PET-P/PVDC/PE, PVC/PVDC/PE, PA/PVDC/PE of combinations of PVC or PA with PE (sufficient thickness of material). Cellophane/PE-, PA/PE-, PVCD-, PET-P/PA/PE-, and PP/PA/PE combinations are used for sausages in evacuated packages.

Packaging without oxygen-withdrawal uses water vapour permeable cellophane (different kinds of raw sausages in natural sausage skins) or films made of PVDC, PE, PVC, and water-repellent cellophane (raw sausages in plastic sausage skins with low water vapour permeability). PS, HDPE, PVC, paper/PE, and PA/PVDC/PE are used for delicatessen, depending on imperishability required.

Keeping quality of products for which desiccation (increase of salt concentration, formation of a specific micro-flora) is possible or even desired, is on principle higher than that of other pickled products; at very best (high degree of dehydration, low oxygen content, protection against light, small surface) keeping time can be up to 4 months at 15°C.

Other pickled or salted meat products have mostly high water content. Processing temperatures are not sufficient to destroy germs (in particular spores); keeping quality is therefore as a rule limited to up to 3 weeks, even at lower storage temperatures (approx. 4 °C).

Sufficient protection against light provided, vacuum-packed bacon can be stored up to 4 weeks at 10 °C.

1.3.5.Portioned deep-frozen fish

Protection against desiccation (frost blight), light and oxygen (oxidation tendency increases rapidly with rising temperatures, particularly in case of fatty fish). Lean fish develops a strawy consistence if stored at insufficient cooling temperature.

Suitable packaging has to be resistant to low temperatures, and to a large extent impermeable to oxygen, odours, and flavours, and must have high water vapour impermeability. Sufficient protection against light is essential, particularly in case of fatty fish.

Products with low sensitivity (breaded or pre-fried fish products) are packaged in printed cardboard boxes. Packages for all other products are made of PE-laminated board (perhaps with separate insertable bags or wrapping films made of PE/cellophane); vacuum packages made of PE/cellophane or PE/aluminium, boil-in-bag packages made of HDPE, PA/PE, PET-P/PE, and shrink films made of PVC and PVDC are also used.

1.3.6.Baked goods

1.3.6.1.Durable baked goods

Packaging of durable baked goods must first of all differentiate according to the product-specific moisture content. For products with little moisture, loss of crispness is usually the dominating loss in quality; additionally, changes in flavour due to oxidative processes, loss of aroma and absorption of foreign odours have to be observed. Microbial spoilage and changes in consistency because of desiccation are additional problems for products with higher moisture contents.

Means of packaging should exhibit low water vapour permeability, diminish the influence of light as much as possible, be nearly gas-tight, and have little oxygen permeability. They must be resistant to flavour, prevent transfer of flavours and odours, and also protect the product from mechanical damages.

PE- or PVDC laminated papers and boxes, weatherproof and/or polymer coated cellophane, combination films made of PE, PVDC, and cellophane as well as aluminium-laminated foils or completely printed films are used in many different ways.

Depending on fat- and water content, these products - if suitably packed - keep quality between 3 and 12 months at 20 °C.

1.3.6.2.Freshly baked goods

Packaging engineering cannot prevent baked goods becoming stale. On the one hand, water vapour discharge should be possible in order to avoid the crust getting stale (balance of moisture content between crumb and crust); on the other hand there has to be a counter action to desiccation and the connected changes in consistency. Too much moisture, however, stimulates growth of moulds and fungus.

In this case packaging has just a hygienic function and the means of packaging selected must have high water vapour permeability but also prevent reinfection as much as possible.

Wrappers, bags, and shrinkable films made of cellophane, PP, PE, and PVC, often perforated in order to provide a better exchange of moisture, are used. More sensitive products with fillings or fruit garnishings are put on specially formed cups or trays which prevent mechanical damage.

Water vapour permeability, fat resistance, grease impermeability, and protection against light must be demanded for fatty fine confectionery. However, at the same time attention must be paid to the fact that the danger of moulding in case of high equilibrium moisture is very high.

Packaging of sterilized cut bread has to be water vapour proof and - even under conditions of sterilization - indifferent to odours and flavours. Suitable materials are PVDC-laminated layers, PE-laminated cellophane, and PE-laminated aluminium foils. Imperishability between 6 and 12 months can be achieved.

1.3.7.Edible oil

Edible oil tends to become rancid in the presence of oxygen. This is actuated and accelerated by the influence of light, particularly in the UV-range. Heavy metallions (e.g. of copper, iron) and manganese induce rapid degradation of edible oils and reduce shelf-life.

Packages should protect against oxygen and light, must be absolutely oil-tight and oil resistant, and should have as little headspace as possible, preferably filled with inert gas.

PVC-bottles offer almost similar good protection as tin cans or glass bottles, provided the special requirements are met.

1.3.8.Dried food

Requirements on packaging materials depend, in the case of dried food mainly on the respective product; however, as a rule some basic packaging requirements must still be observed:

- water vapour- and oxygen impermeability
- protection against light
- resistance to flavour
- fat resistance (for soup cubes, meat, fish, dried soup, etc.

Sugar and salt are on the contrary rather insensitive, except against high humidity.

2.Plastics in Packaging Production

2.1. Fundamentals of plastic application in packaging (1) (2)

Favourable properties like

- low specific gravity,
- easy shaping,
- durability,
  good barrier properties,
  visibility of content,
- suitability for many purposes, and
- wide range of application by use of additives and combinations of different plastics as well as combinations with other materials (composites)

and their special combinatin meet the many demands for the packaging of foodstuffs. Because of the wide variety care must be exercised in the choice of film used for any particular product. And knowledge of the barrier properties of the most common films is therefore essential (Fig. 2.1., 2.2., 2.3.).

Plastics have many uses as means of packaging: wrappers, bags, and pouches are made from flat and tubular films; cans, cups, and trays are produced by thermoforming; many articles are made by blow- or injection-moulding. Other fields of plastics application are shrink and stretch films, wrapping tapes and tear strips. Additives like

- plasticizers;
- processing stabilizers;
- lubricants;
- light stabilizers;
- toners, fillers, and dyestuffs;
- softening and antistatic agents;
- optical clarifiers;
- impact tougheners

extend the properties of plastics and, above all, improve their processing:

However, additives should be applied as sparingly as possible.

The still increasing variety of plastics (particularly in technical use) and the wide range of application make a comprehensive and still short description difficult. Only a brief review can be given in this context.

2.2.Special procedures in plastics packaging

2.2.1.Stretching

The utility of plastic films can be improved for special purposes by *stretching*. Stretching brings about an orientation of the molecular chains and increases resistance lengthwise, while diminishing the stretching direction crosswise. *Biaxial stretching* brings about a general orientation. Brittleness is reduced, and there is an augmentation of rigidity and shock resistance. Transparency and constancy of thickness is improved, permeability against gases and vapours is reduced.

2.2.2.Shrinking

Shrinking is basically a relaxation of film-tension (induced by stretching) by heat. The amount of shrinkage and shrinking tension depends on applied temperature and on the level of induced reversible deformation by stretching.

The most commonly used films in shrink wrapping are specified in table 2.4. by key data for specific properties.

Shrinkage of film changes its properties, affecting some characteristics more than others.

Shrinkable films are used in food packaging for many reasons. One advantage of shrink wrapping is the ability to wrap awkwardly-shaped articles such as poultry, ham, etc. In some cases it is possible to be more economically efficient: Trays are usually provided with a peripheral rim or bed in order to wrap the tray with just enough film to cover the top and to shrink round the rim instead of covering the tray entirely with an ordinary overwrap. Shrink wrapping as a means of packaging for shipment becomes more and more important for economically efficient packaging, for distribution.

A further advantage of shrink wrapping over normal overwraps or bags is an effective reduction of the risks of mould growth or "freezer burn" (due to surface dehydration).

2.2.3.Heat-sealing methods

With the use of thermoplastic films, surface and weld-type sealing have become important procedures in

	abbreviation	wraps	bags, pouches	shrink film	stretch film	cups and trays	bottles	closures	lining	containers and crates	composite packaging materials	cushioning materials (foamed)
cellulosics	-	x	x								x	
low density polyethylene	LDPE	x	x	x	x		x	x			x	
high density polyethylene	HDPE	x	x			x	x	x		x		
polypropylene	PP	x	x			x	x	x			x	
polyvinyl chloride	PVC	x		(x)	x	(x)	(x)	(x)*			x	
polyvinylidene chloride	PVDC								x		x	
polystyrene **)	PS					x		(x)				x
styrene bivinyl***)	SB					x					x	
polyamides	PA	x	x								x	
poly urethane	PUR											(x)
ethylene vinyl alcohol	EVOH										(x)	
poly carbonate	PC					(x)	x					
polyethylene terephthalate	PET	(x)	(x)			(x)	x				x	
ionomeres ****)	-	(x)	(x)								(x)	

(x) only in special cases / rarely used
* compound material for bottle closures
**) transparent
***) impact resistant, opaque
****) e.g . surlyne

Table 2.1. Examples for the use of plastics in food packaging (3)

	LD-polyethylene	HD-polyethylene	polypropylene	polystyrene	polyamide	polyester	EVOH	PVDC	polycarbonate	ionomeres	aluminium foil	cellulose board	cellulose paper
high temperature resistance		x	x		x	x			x		x	x	x
great strength			x*)	x*)	x*)	x*)				x		x	x
high stiffness				x								x	
low water vapour permeability	x	x	x			x	x	x			x		
low oxygene permeability					(x)	x	(x)	x			x		
good weldability	x	x		x				x		x			

*) biaxially oriented
(x) moisture dependent

Table 2.2. Dominating packaging properties of plastic films and aluminium foils as well as board and paper for the production of composite material (3)

	density (g/cm^3)	rigidity (E-module) (N/mm^2)	tensile strength (N/mm^2)	elongation at rupture (%)	temperature resistance (° C)	water vapour permeability $\frac{g\cdot mm}{m^2\cdot d}$	O_2-permeability $\frac{cm^3\cdot mm}{m^2\cdot d\cdot bar}$	CO_2-permeability $\frac{cm^3\cdot mm}{m^2\cdot d\cdot bar}$
cellulosics	1,10-1,45	~ 3000	20-100	6-70	40-90	0,10-40[2]	-	-
LD-polyethylene	0,92	~ 200	8-10	20-700	80	0,16-0,64	130-300	750-1780
HD-polyethylene	0,96	~ 1000	17-30	15-100	105-130	0,16-0,17	50-110	120-370
polypropylene	0,91	~ 1400	200-350	100	90-130	0,07-0,16	35-90	170-320
rigid-PVC	1,35-1,40	~ 3100	50-60	2-40	65-80	0,20-0,80	2-7	5,3-11,0
soft-PVC	1,16-1,35	~ 40	7-35	200-450	65-80	3,2-15	-	-
PVDC	1,65-1,72	~ 400	21-35	bis 250	70-95	< 0,2	< 0,4	< 2,3
polystyrene	1,04-1,06	~ 3000	45-55	3-5	70-80	2,00-2,50	100-190	330-1200
polyamide	1,12-1,14	1800	40-65	80-180	80-105	0,90-1,80	0,6-6,0	2,5-10,2
polyurethane	1,20	-	-	-	50-80	-	-	-
ethylen vinyl alcohole	1,15-1,20	3700	50	40-90	-	≤ 1,50[1]	≤ 0,04[1]	≤1,10[1]
polycarbonate	1,20	2300	60	60	100-150	0,25	65-97	450-520
polyester	1,20-1,40	4000	40-60	2-4	90-120	0,32-3,00	0,9-4,5	5,7-11,0
ionomeres	0,93-0,97	200	14-16	350-400	70-75	-	-	-

1) in dry condition

2) depending on coating and moisture content

Table 2.3. Material key data (standard values) of plastics according to different bibliographical references (3)

	Maximum Shrinkage (%)	Shrink Tension Range N/mm^2	Film Shrink Temperature Range (°C)	Commercial Tunnel Temperature Range (°C)	Sealing Temperature (°C)
Low density polyethylene	15-50	0,4-4,0	90-120	120-150	150-200
Polypropylene	70-80	2,1-4,2	105-140	150-230	160-200
Polyvinylchloride	50-70	1,0-2,1	65-150	110-155	135-175
Polystyrene	40-60	0,7-4,2	100-130	130-160	120-150
Polyester	40-50	4,9-10,5	70-120	110-155	-
Rubber hydrochloride	30-50	1,0 -2,5	65-110	110- 150	80-120
Polyvinylidene chloride co-polymer	30-60	1,0-1,5	65-110	110-150	80-120

Table: 2.4. Properties of shrinkable films (1) packaging. The main advantage of these joints and closures is that they have about the same barrier qualities as the packaging material itself. Especially in food packaging for reasons of hygiene and keeping-quality the package must be impermeable to dust, micro-organisms, liquids, water vapour and/or oxygen.

Weld type sealing is the fusing of two unsupported thermoplastic films through the effect of heat and, where necessary, also pressure. Immediately after the welding process all welded joints are soft and without any mechanical strength. The original strength is reacquired after cooling off to about room temperature; the fusing area must not be stressed during this cooling period. Most of the sealing equipment include means to cool the seal after welding by pressing the seal between to cold metal bars. Only those methods in general use in the packaging industry will be discussed here.

Surface type sealing is the fusing of the interface thermoplastic coating of a multiple-layer packaging material by the effect of heat and pressure, where at least one layer of the laminate - the supporting layer - does not turn plastic at sealing temperature.

A freshly made seal made by face-to-face sealing is far less critical in the hot stage than a fused seal because the supporting material is not changed in structure. For the same reason it is unnecessary to cool the seal under pressure. Very thin thermoplastic films (e.g. heat sealable lacquer coatings on regenerated cellulose film or aluminium foil as supporting material), cannot produce drip proof and gas proof seals.

With the *thermal impulse system* the films are clamped between two cold metal bars, fused by a short heat impulse and cooled down under pressure. Heat is supplied by thin strips of resistance metal which are attached to the bars, but electrically insulated from them. The metal strips are heated up by a short current impulse. Afterwards the heated strips and the fused films are rapidly cooled down due to the good thermal conductivity of the water cooled metal bars. The jaws are released, giving access to the fused seal which has already cooled off properly and reached its optimum strength.

One-sided heat sealing is usually sufficient for films up to 20 µm, but not for thicker films. Sealing with heating elements on both jaws have the advantage of requiring lower temperature for the same heat transfer. The seals produced by the thermal impulse system are of excellent quality, not only in regard to their barrier qualities, but also in regard to their mechanical strength. This procedure is not only used in large, fully-automatic packaging machines, but also in smaller semi-automatic machines for the production and closure of flat or square bags and plastic pouches. There are also more simple manually-operated machines available for the sealing of packs and plastic pouches.

With the *band sealer system* the films to be fused are clamped between two endless steel bands and transported consecutively between sets of heating and cooling jaws. These thin steel bands have high thermal conductivity; thus heat passes practically undiminished into the film, allowing consequently a high sealing speed ranging from 10 to 20 meters per minute. If necessary, the endless steel bands with the welded seal in between may be pressed together between the heating and cooling zones by a pair of pressure rollers. Band rotary sealers are specially suited for the sealing of filled flat bags of widely different dimensions, since the seals can have practically any desired length. Such machines are available for semi-automatic or manual operation.

Thermal impulse sealing and band rotary sealing are not only feasible for sealing unsupported films, but also for sealing laminated packaging materials.

Hot wire, rod or flame radient sealing is only applicable to thermoplastic films which can tolerate high temperatures for a short time and which have also low viscosity in the fused stage. It is mostly used for the manufacture of bags and pouches from PE-tubes. Plastic film tube is cut at the desired spot by a glow wire, heated metal knife, or small gas flame, the opposing parts of the tube being fused together in the same operation. In advanced machines the welded seal can be pressed between two cold metal bars to ensure that the seal is drip proof. This system may only be used for the fully automatic or semi-automatic processing of flat bags and plastic pouches from tubular PE-films.

The *hot bar system* is the most popular system, because it is uncomplicated and practically fool-proof. The packaging material is clamped between two permanently heated metal jaws; the joint is effected after a short dwell time. In processing thin films it suffices to heat only one jaw which presses the packaging material against a cold, frequently resilient supporting jaw covered with teflon or silicone rubber. Such seals cannot be expected to be water vapour-, gas- or drip-proof.

The hot bar system is used in

- automatic packaging machines for the production and sealing of packs and for the sealing of overwraps
- sturdy small manually operated machines for the sealing of bags and overwraps.

The inter-relationship of temperature, dwell time and pressure must be understood in order to avoid defects in weld and surface type sealing.

2.3.Properties of the most important plastics for food packaging (1)(2)(3)

2.3.1.Cellulosics

Transparent, low restoring force, high rigidity, low friction, advantageous cutting qualities, excellent printability, impermeable to oil, resistant to tears and liquids, bondable, with a tendency towards shrinking and swelling. Low permeability to water vapour and gas permeability dependent on moisture contents. Reduction of water vapour- and gas permeability by varnishing with cellulose nitrate varnish or, for even better impermeability and sealability, with PVDC. Used as wrap, for bag production, and as laminating material for packaging sweets, bread, baked goods, cheese spread, cream or soft cheese, grated cheese, etc.

2.3.2.Low Density Polyethylene (LDPE)

This is the most commonly used plastic film for packaging. Tough, transparent, low permeability to water vapour. Chemically very inert, practically odour- and tasteless. High tear resistance and impact strength, usable in a wide temperature range, very good sealability, excellent shrinkability. LDPE possesses relatively high permeability to gases such as oxygen and carbon dioxide and is therefore unsuitable for packaging foods that are subject to oxidation or as film for vacuum packaging. It is also permeable to many essential oils, odours and flavours. Some oils cause cracking of polyethylene when the material is stressed.

LDPE film can be printed by normal processes such as flexographic and silk screen after surface treatment (gasflame, coronary electrical discharge).

LDPE films are used for bread wrapping, frozen food, dried skim milk, sausages and meat pies. In the case of wrappers for bread or similiar products too good a moisture vapour barrier must be avoided because of the risk of mould growth and softening of the crust. It is used for frozen food because it is cheap and resistant to low temperatures. For dried milk packaging it is used in multi-layer bags.

2.3.3.High Density Polyethylene (HDPE)

HDPE has a 2 - 3 times lower permeability to water vapour and gases as LDPE. It is also more resistant to the passage of odours and flavours. It has higher tensile strength, but lower impact strength. It can be steam sterilized because the softening point is above the boiling point of water.

Because of its high softening point and its good barrier properties, HDPE is used for packaging meals which are cooked in the bag (before serving). It is also used for the production of bottles, transport boxes, and cascets.

2.3.4.Polypropylene (PP)

PP film is usually produced by extrusion into a chilled roller and in this form is referred to as "cast" film. The film so produced has a good standard of clarity. Its permeability is similiar to that of HDPE, but it can be lowered by biaxial orientation of the film which improves its properties. PP has an even higher softening point than HDPE but tends to brittleness at lower temperatures.

The cast film is used for bread wrapping and the manufacture of side-weld bags because it is cheaper and has better heat seal properties.

Heat sealing of biaxially oriented PP is difficult because orientation gets lost (and hence strength). One way of overcoming that problem is multipoint sealing but such seals are not completely gas tight. Another way is to coat the film with a lower melting polymere (PVDC, modified PP). Such films are applicable for wrapping cheese, bacon, cooked meats, and especially foods sensitive to moisture and oxygen, such as biscuits and potato crisps.

2.3.5.Polyvinyl chloride (PVC)

PVC has a low permeability to oxygen but is more permeable to water vapour than LDPE. It is highly resistant to greases and oils, including essential oils, This makes PVC suitable for food with strong odours and flavours (e.g. fish), and with high oil content (e.g. margarine).

Unplasticized PVC can be vacuum formed, in thicknesses down to 50 µm for insert trays for boxes of chocolates, biscuits and small cakes, for cups and trays for fatty goods. With extrusion blow moulding hollow articles such as bottles are made.

Plasticized PVC is a desireable packaging material for special purposes because of its pliability but it should not be used for fatty or oily foods (migration of plasticizers).

2.3.6.Polyvinylidene chloride (PVDC)

PVDC was the first shrink wrap in use. The film has an extremely low permeability to water vapour. It has been used for short-term wrapping of cheese and as shrinkwrap for ham and frozen poultry. Because of its low gas permeability it is also used for vacuum packaging.

2.3.7.Polyethylene terephthalate (PET)

PET shows low gas permeability, while water vapour permeability is slightly higher than that of LDPE. It forms extremely strong films especially when oriented. PET is fat and oil resistant, odour and flavour tight.

It is mainly used for thermo forming, the production of hollow articles, and for processing crease proof and tear proof composite films (for bag production its impermeability to gas can still be increased by metalization).

2.3.8.Polystyrene (PS)

PS is available as an oriented film that can be vacuum formed or used as shrink wrap. It is a very poor barrier to moisture and fairly permeable to gases. It is, therefore, mainly used for packaging fresh produce which needs a "breathable" film. One of its main advantages is the fact that the film has a sparkling clarity.

2.3.9.Polyamides (PA)

PA has high transparency, abrasion- and scratch resistance, durable bending- as well as mechanical strength; it is resistant to fats, essential oils and higher temperatures, odourless, free of flavour, has good impermeability to gas, but lesser impermeability to water vapour and fragrances. PA tends to swell by influence of moisture, which increases also its impermeability. Stretching increases tear strength and impermeability.

PA is used in composition with other plastics or aluminium for production of vacuum packaging, and also for wrapping (fresh meat) bags (boil-in-bag package), and for trough-shaped packages (e.g. for fresh cheeses).

2.3.10.Polyurethane (PUR)

PUR is often used as mixing adduct with glycol (that improves flexibility and plasticity). However, it is mainly used foamed as cushioning material.

2.3.11.Ethylenevinyl alcohole (EVOH)

In dry atmosphere EVOH shows the highest impermeability to gas, but is very hydrophile. Therefore it can only be used as barrier layer in composite films. The use of EVOH for gas-tight packages is at time in the stage of development.

2.3.12.Polycarbonate (PC)

PC is transparent, tenacious and can be heat-sealed; it is comparatively unbreakable, heat resistant, and shows low water vapour-, but high gas-permeability. PC is used in packaging for the production of bottles (for pasteurized milk) and heat resistant films to fry meat and poultry in bags.

2.3.13.Ionomeres

ionomeres are copolymerisates of ethylene- and carboxyl-groups, show good transparency, high tearing- and puncture resistance (particularly at low temperatures), resistance against grease and organic solvents, and good heat-sealability.

Ionomeres are used in composite films with cellolosics, polyamids, and polyester for vacuum packaging (cheese, meat products, etc.) boil-in-bag packages, and also for the production of hollow articles.

3.Quality Control

3.1.Introduction

Packaging materials and means of packaging have to meet a number of requirements, particularly in food packaging; these requirements have to be examinable. A great number of specifications (drawn up by public authorities and economic institutions) exist for this purpose in order to enable an impartial evaluation of packages.

But before making a test for packaging materials or packages, it is necessary to be absolutely clear about its purpose. This remark seems superfluous; nevertheless companies not infrequently have performed numerous tests, either without drawing any conclusion from them or without recognizing that they have little or no relation to the purpose of testing. In both cases the test is useless and waste of money. The application of standard tests guarantees a high quality of the packaged products, a factor equally important for export and home consumption.

There follows a description of frequently used tests. Special attention will be paid to methods which permit a satisfactory evaluation with the aid of inexpensive apparatus. This is rather important, because laboratories are usually only poorly endowed when a new industry is in the making.

The main purposes for testing packaging materials or packages are

- comparison with competitive materials
- comparison of the current supply of material with the quality that was supplied the first time; also regular checking of uniformity in new supplies of packaging materials.
- quality checks during the production of packaging materials or packaged commodities
- evaluation of the suitability of a packaging material for a certain purpose.

The last-named instance is of special importance, since the developement of new packaging materials is based on such tests and also since these tests play such an important role in their acceptance for special packaging purposes. In these tests these difficulties have to be dealt with, especially with regard to proper simulation of the hazards which packages may encounter.

For regular quality control it will be best to try to manage with simple tests, especially in cases where the suitability of the packaging material for its special purpose has already been proved elsewhere. The number of tests to be made and the percentage to be tested depend on the required precision of the test result. Such precision is contingent on financial considerations and also on the risk which the producer or distributor of a faulty package has to run. In cases where the contents of a faulty package can spoil before the usual turnover time or, still worse become a hazard to the health of the consumer, or where, for instance, a leaking package is liable to ruin a score of other packages, the test will have to be more severe than in cases of simple paper bags or cartons to be used for less sensitive products.

3.2.Methods and Standards

Since it is impossible to present here a comprehensive outline of all prevalent testing methods for tests for plastic packaging materials and means of packaging, there follows just a summary of the most important ASTM- and DIN methods and standards.

3.2.1.Thickness
DIN 53370

Determination of thickness occurs with a dial gauge, one of whose measuring areas is flat grinded while the other one is bended in a spherical indentation in a radius of 30 - 50 mm. Contact pressure must be between 0,1 and 0,5 N.

The accuracy of measurement has to be 0,2 µm for material thicknesses of 5 µm, for thicknesses about 100 µm the accuracy has to be 2%.

The method serves for testing smooth, not embossed plastic films and should also register possible differences in thickness of a film sheet.

3.2.2.Tensile strength and elongation
ASTM D 882

The testing machine consists of clamps to hold the sample, some means of gradually increasing the load on the specimen until it breaks and indicators which show the load and the amount of elongation.

To perform the test measured, gauged specimens are clamped into the testing machine and stretched until they break.

Tensile strength is usually reported in pounds per inch of width necessary to pull the paper apart. For films, the usual units are pounds per square inch of original cross-sectional area. Tensile strength is quite literally the amount of force necessary to pull a material apart. The elongation is the amount a material will stretch before breaking.

Tensile strength is a most important value for materials used in applications such as heavy-duty bags. A large value for elongation is an index for toughness, since it indicates that a material will absorb a large amount of energy before breaking.

3.2.3.Tear strength
ASTM D 1922

A tear tester has a stationary clamp and a moveable clamp on a pendulum, means for holding this pendulum in a raised position, then quickly releasing it, and a scale that registers the arc through which the pendulum swings.

Samples of paper or film are clamped into the tester and nicked to start the tear; then the pendulum clamp is released. This tears the sample and the scale registers the arc. As the arc is proportional to the tear strength of the sample, calibration of the arc gives the tear strength.

Tear strength is reported in grams. It is the force necessary to continue tearing a sample after a nick has been made.

This test is very important for all films as well as for paper. High tear values may be needed for machine operations or for package strength. However, low tear values are necessary and useful for the easy opening of some package types.

3.2.4.Impact strength
ASTM D 256

The pendulum impact tester can be used to measure impact strength of papers, boards and films. An impacting head on the end of a pendulum is swung through an arc into and through the sample. The tester has a means of measuring the difference between the potential energy of the pendulum at maximum height in free swing and the potential energy of the pendulum after rupture of the sample. This difference in energy is defined as impact strength and is reported in units of kilogram-centimeters. It is useful in predicting the resistance of a material to breakage from dropping or other quick blows.

A test similiar in scope, method, and significance is the dart drop test (ASTM D 1709). A weighted dart is dropped from standard height on to the taut sample. Significance and purpose are the same as in the pendulum test. Dart unit is the weight of the dart in grams that breaks the sample 50% of the time. These tests give an index of a material's dynamic strength and approximate what will occur when package is dropped.

3.2.5.Bursting strength
ASTM D 2529, D 2738

The bursting strength tester, commonly called a Mullen tester, has clamps for holding the sample over a rubber diaphragm and a motor that forces a liquid into a pressure chamber under the diaphragm at a rate of 95 ml per minute.

The sample is clamped in place and the motor started. The liqid, usually glycerine, is forced against the diaphragm until the sample ruptures. The pressure of the liquid is indicated on a bourdon gauge.

Mullen burst strength is reported in points bursting strength, which is the hydrostatic pressure indicated on the gauge. It is of importance in material selection for bags and is one of the tests that forms the basis of determining paper "durability".

This test is originally designed for paper and board but sometimes used for plastic materials in pouches-making. It is simple and fast, but its exact significance as an index of practical perfomance has been questioned.

3.2.6.Compression strength
ASTM D 1164

The ring crush compression test is run on a tester which has upper and lower platens (flat metal plates), means for exerting force on a specimen placed between the two platens, and devices for measuring load applied.

A strip of sample is inserted on its edge in a circular groove in a specimen holder on the lower platen. The crushing force is applied to the long edges of the sample until it collapses. The maximum load is recorded as ring crush strength.

Ring crush strength is reported in pounds force. This test measures the resistance of paperboard to edgewise compression.

Corrugated and solid fibreboard containers are subject to crushing forces in shipment. This test indicates edgewise rigidity of the board. This information helps board manufacturers to provide materials with the amount of crushing resistance desired in the finished container.

This test is, therefore, an index of the stackability of filled containers.

3.2.7.Fold endurance
ASTM D 2176 Method B

The M.I.T. fold endurance tester (there are others but the M.I.T. is preferable as it is applicable to materials of any thickness) has an upper spring load clamp which moves only up and down, an oscillating folding head which supports the smooth, folding surfaces, a driven device to provide rotary oscillating motion to the folding head, and a counter to register the number of folds.

The sample is clamped into the folding head and the upper spring-loaded clamp is depressed by a weight equivalent to the desired tension on the sample. Then the sample is clamped into the upper clamp and the tension applied. The motor is started and the sample folded until it is severed at the crease.

Fold endurance is reported as the number of double folds required to sever the sample.

This test was developed for paper and is an index of durability for some uses, but may be applied even for plastic sheet materials.

3.2.8.Water-vapour transmission
ASTM E 96, Method E

Apparatus for WVT testing includes test dishes, analytical balance, a desiccant, and a temperature/humidity controlled test chamber. Water vapour from the chamber permeates the test material to absorb on the desiccant. Before and after weights of the test dish show the water vapour transmitted.

The usual units of WVT are grams of water passing through one square meter of test material per twenty-four hours at a specific temperature and humidity differential. WVT is significant for packaging products that must be protected from gaining or loosing moisture to the surroundings. ASTM D 1251 is a related method that tests the actual package.

3.2.10.Gas transmission
ASTM D 1434

Specially constructed cells are used to measure gas transmission rate. After a film sample has been clamped into the cell, test gas is flushed through chambers on both sides of the sample. Test gas is admitted to one side of the sample, the test chamber on the other side is evacuated and gas is allowed to permeate through the film sample into the evacuated chamber for a measured length of time. Using the geometry of the cell and the film sample, with the measured pressure and temperature of the test gas which permeated the sample, the gas transmission rate can be calculated. Gas permeability is usually reported in cubic centimeters of the gas that passes through a square meter of film in 24 hours when the gas pressure differential on one side of the film, at a specific temperature, is one atmosphere higher than that on the other side.

The gas transmission rate is vital in vacuum and gas packaging for fresh produce items that must breathe.

3.2.14.Influences of odours and flavours
DIN 10955

Odours or flavours migrating from the packaging material respectivly odours and flavours from the surroundings permeating into the product are determined by sensory evaluation.

It is possible to examine either the (operationally defined) headspace of the packaged product (odour transmission from the packaging material or the surroundings into the headspace) or a flavour transmission from the tested material or the surroundings into a testing substance.

The particular procedures to be used cannot be explained in this context, but there are exactly defined tests for a multitude of applicable cases.

Interpretation and statement of test results can be gathered from appropriate testing patterns.

3.2.15.Haze
ASTM D 1003

The haze of transparent packaging materials is measured on a special hazemeter which has an incandescent light source and geometrically arranged photocells that measure transmitted and scattered light.

The sample is placed between light source and photocells. The amount of light transmitted by the sample, the light scattered by the sample and the instrument and the total incident light are measured. From these values the percentage of transmitted light which is scattered can be calculated. The hazemeter measures these variables and interrelates them so that the percentage of the scattered light can be read on the meter. This test is important to products or in uses where true colour and visability are required.

3.2.16.Specular gloss
ASTM D 2457

Gloss is measured on a glossmeter. This instrument has an incandescent light source and a photosensitive receptor that responds to visible light.

Light shines onto the sample at a specified angle. Some of it is reflected onto the photosensitive receptor. The fraction of the original light that is reflected is the gloss of the sample.

Gloss is an important merchandising factor and this test makes it possible to specify and control this surface characteristic to assure the desired effect.

3.2.17.Light transmittance
DIN 10050 Bl. 9

Light transmittance is determined with an Ulbricht cell in a wavelength range from the near UV up to the visible light. Light intensity is measured at the free inlet of the cell and afterwards with the sample fixed in front of the inlet.

If the sample's light transparency is influenced by moisture content, then the sample has to be conditioned prior to measurement.

3.2.18.Microbial content
DIN 10050

The testing material is put on a nutrient agar in petri dishes and softly pressed against it with a Drigalski-spatula. The sample part facing the product has to lie upwards; a thin layer of nutrient agar (48 °C) is poured on it.

Evaluation takes place after three days of incubation at 25 °C.

Bacterial count is determined macroscopically by a count of the colonies.

4. Annex A: Literature

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Plastics in Packaging
(Plastic Technologies for low cost Packaging Application to Developing Countries)

Part II
Plastics Technology

Content

1.Plastic materials

1.1.Classification

1.1.1.Oscillation Twisting Test

Elastic properties, expressed by the shear-modulus, depend on the temperature. SCHMIEDER-WOLF based a measuring method for the classification of polymers according to a physical interpretation on this dependance. This method is called oscillation twisting test, based on DIN 53 445, and gives the temperature functions of the shear modulus. The G-T-function results in the classification of plastics.

1.1.2.Thermoplastics

Thermoplastics are not cross-linked and so their molecules are principally movable against each other. Below glass transition temperature T_g there is no micro-Brownian motion but up to the decomposition temperature T_z the consequence is macro-Brownian motion. Thermoplastics are the only materials, whose shear modulus disapears above the glass transition temperature and makes processing of the melt possible.

Fig.1.1. shows the functions for amorphous and crystalline thermoplastics.

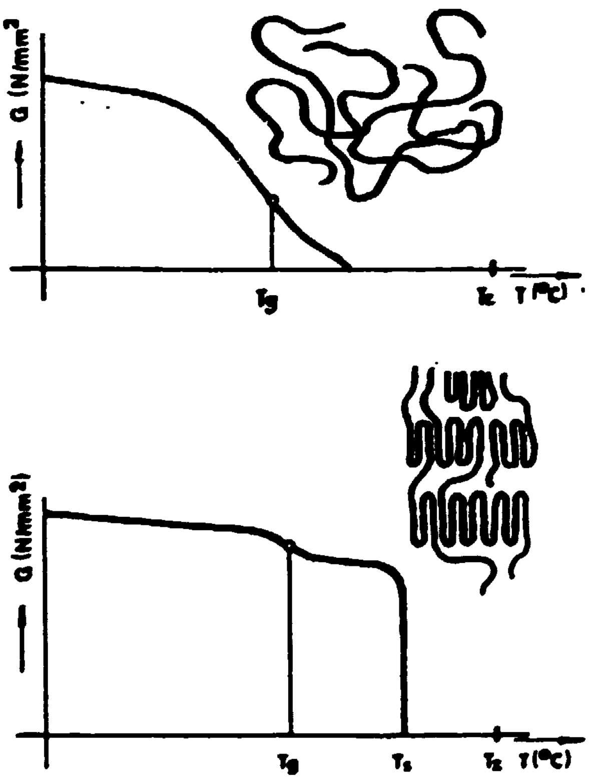


Fig.1.1. Definition of thermoplastics by G-T-function

1.1.3.Thermosets

Cured thermosetting materials are completely cross-linked, and thus their molecules can never fully move at any given temperature. Their shear moduls is never less than 10 N/mm^2. This means that cured thermosets are not fusible and have a relatively high heat distorsion stability and a higher shear moduls. The glass transition temperature T_g is above 50°C according to definition. Up to this temperature, even at room temperature, thermosets are energy-elastic. Micro-Brownian motion occurs above 50°C, macro-Brownian motion is not p'ssible (Fig.1.2.).

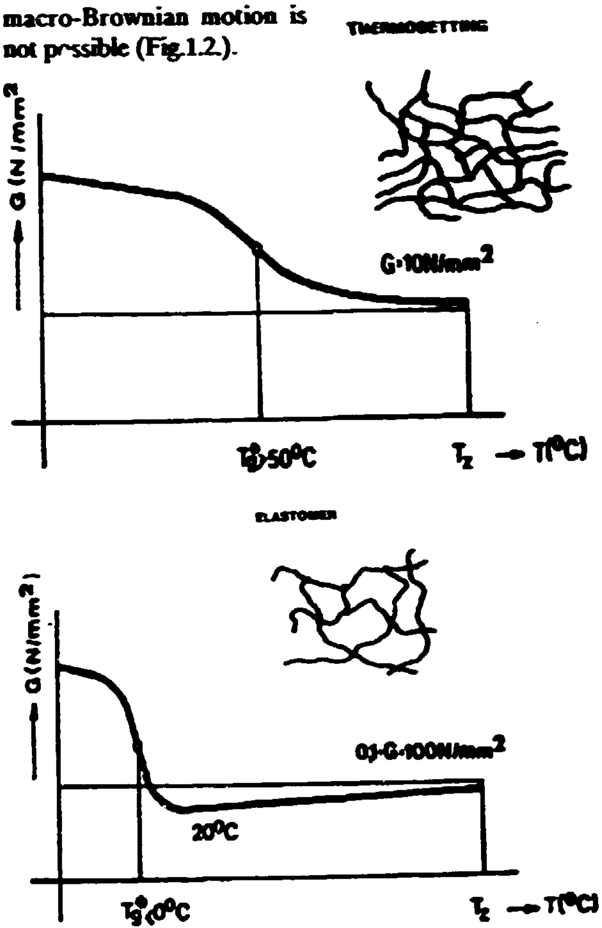


Fig.1.2. Definition of thermosets and elastomers by the G-T- function

1.1.4.Elastomers

Cured elastomers are completely, but loosely cross-linked, and their molecular segments are able to move even at low temperatures. Because of the cross-linked structure a certain flow may occure at low temperatures. So it is evident that this material has a low E-modulus. The definition of the glass transition temperature T_g is below 0°C. Elastomers are entropy-elastic above this temperature, even at room temperature (Fig.1.2.).

1.1.5.Thermoelastics

At present this group only includes PMMA and some PUR-compounds. The definition is basically the same as with elastomers, but instead of a chemical cross-linking there is a mechanical cross- linking, and a glass transition temperature T_g above 0°C.

1.1.6.High Temperature Resistant Polymers (HT-Plastics)

Although HT materials are not cross-linked they behave in the oscillation twisting test like thermosets because of the low molecular movability.

1.2. Survey

In order to achieve a better survey in the classification of plastic materials, the economical aspect will also be considered besides the technological point of view (Fig.1.3.).

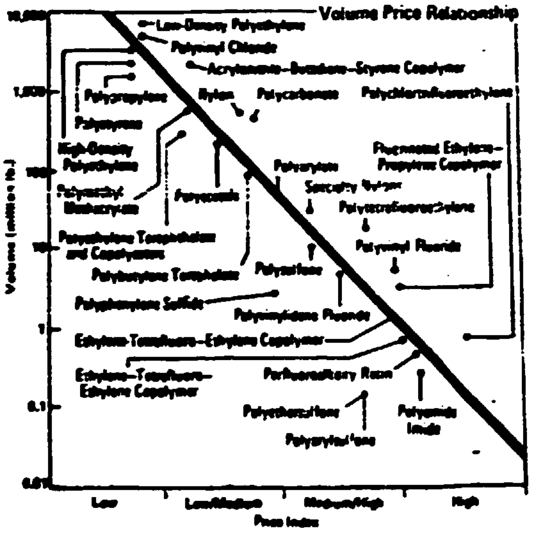


Fig.1.3. Volume price relationship of plastics.

Thus it is necessary to introduce terms as "standard thermoplastics" ("commodity plastics"), "engineering thermoplastics", and "high temperature resistant polymers". There is no definite principle as to which plastic materials may be ranked under any of the terms mentioned above. Production statistics of industrial countries, however, show that the term standard plastics partically refers to the polyolefines PE and PP, styrene polymers (PS + copolymers) and PVC with copolymers, because at present these groups of materials alone amount up to more than 75% of the total plastics production.

"Engineering thermoplastics" and "High temperature resistant polymers" are of less importance by quantities but because of their special characteristics they contribute substantially to the technological and economical success of plastic materials.

Finally, there is the group of experimental products with tailor made characteristics. Commercially, they are produced in such small quantities that they have not been considered within the scope of this manuscript. In this paper the following privat practical classification is introduced:

- Thermoplastics:
  - Standard thermoplastics
    - Ethylen polmers (PE-LD, PE-LLD, PE-HD, PE-HMW, PE-UHMW, EEA, EVA, EMA)
    - Polypropylenes (PP)
    - Styrene polymers (PS, BS, SAN, ABS, ASA, SMA)
    - Vinylchloride polymers (PVC-U, VCVAC, VCVDC, PVCC, PVC-P)
  - Engineering thermoplastics ($E > 2500\ N/mm^2$, $\sigma > 50\ N/mm^2$, $T > 100°C$)
    - Polyamides (PA 6, 66, 610, 612, 11, 12, 6-3-T)
    - Linear polyesters (PETP, PCT, PETG, PBTP, PAR)
    - Polycarbontes (PC)
    - Polyacetales (POM, PEOX)
    - Polyphenylenoxides (PPO)
    - Polphenylensulfides (PPS)
    - Sulfone polymers (PSU, PPSU, PES)
    - Polyetherketons (PEK,PEEK)
  - Specialty Thermoplastics:
    - Cellulosics (CA, CAB, CB, CP)
    - Specialty polyolefines (PB, PMP, Ionomer)
    - Vinylidenchlorid polymers (PVDC)
    - Thermoplastic fluoropolymers (PCTFE, ECTFE, ETFE, FEP, PFA, PVA, PVDF)
    - Thermoplastic polyimides (PI)
    - Thermoplastic elastomers (TPE)
- Thermoelastics:
  - Acrylics (PMMA, AMMA, MBS)
- Thermosets:
  - Unsaturated polyesters (UP)
  - Epoxies (EP)
  - Polyurethanes (PUR)
  - Phenolics (PF)
  - Aminos (UF, MF)
- High Temperature Resistant Polymers ($T > 250°C$)
  - Polytetrafluoroethylenes (PTFE)
  - Thermosets polyimides (PI)

1.3.Standard Thermoplastics

1.3.1.Ethylene Polymers

$$-\left[-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}- \right]_n-$$

Standardization: ISO 1872
(LDPE, LLDPE, HDPE)

Significant properties: Density 0,918-0,960 g/cm^{3}unpolar, crystalline (40%-80%), opaque, T_m = 105 to 135°C, excellent electrical insulation properties, no HF-reaction, electrostatic load, excellent chemical resistance ("unsoluble" below 60°C), high gas permeability, low water vapour permeability, physiologically indifferent, crazing in contact with tensides.

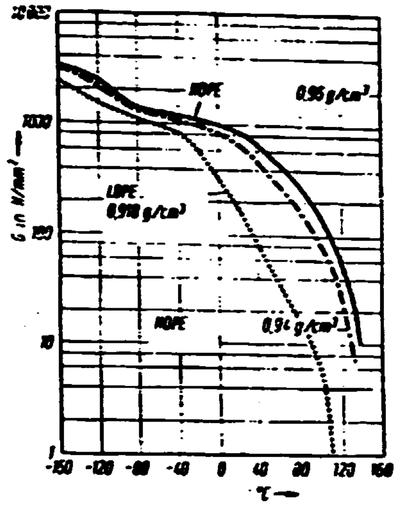


Fig.1.4. G-T-function of PE

Property	Density ↑	MFI ↓ (M ↑)
Tensile strength	↑↑	↑
E-moduls	↑↑	↑
Hardness	↑	↑
Melt temperature	↑	-
Brittleness temperature	↓	↓↓
Impact strength	↑	↑↑
Swelling	↑	↓
Permeability	↓	-
Crazing	↑	↓↓
Transparency	↓	-
Fluidity	↓	↓↓

Fig.1.5. Properties of PE depending on density and MFI

Specialty grades:

LLDPE (linear low density PE): higher impact and tear strength, higher melt temperature, lower strains in film blowing (linear molecules relax and slide by each other without developing significant stresses), requirement of long barrel machines. Example of application: pakkaging films.

HMW PE (high-molecular-weight PE): M_w between 300 000 and 5 000 000 g/mol, high performance properties, excellent crazing resistance, impact strength, long-term strength, chemical resistance. Example of application: Containers for dangerous goods.

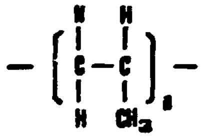
UHMW (ultrahigh-molecular-weight PE): M_w between 3 to 6 millions g/mol, highest abrasion resistance, exceptional impact resistance even at cryogenic temperatures, low coefficient of friction, excellent crazing and chemical resistance, fatique resistance. Mainly processed by a modification of the compression molding technique. Example of application: pumps and valve parts in the chemical industry.

Crosslinking PE: Crosslinking by organic peroxides or by radiation, network structure, exceptional high impact resistance and crazing resistance. Example of application: floor heating pipes.

Important processing techniques: Injection molding (T_p = 160-300°C, T_c = 20-70°C, s = 1,5-4%), extrusion, blow molding, thermoforming, sintering, compression molding, rotaional moul ding, machining, welding (impulse welding), bonding only with surface treatment (flamming, corona-discharge, chemical treatment.)

1.3.2.Polypropylenes (PP)

Standardization: ISO 1873



$$-\left[-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}- \right]_n-$$

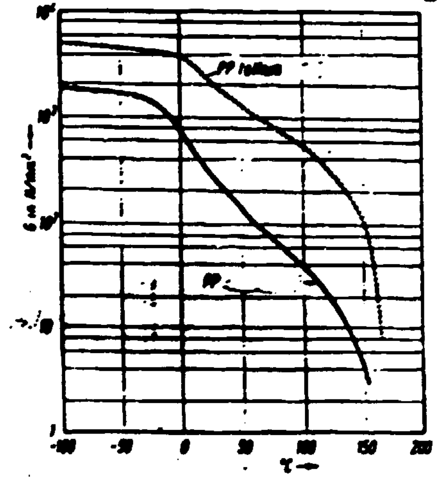


Fig.1.6 G-T-function of PP

Significant properties: Density 0,90 g/cm^3, unpolar, crystalline (60-70%), opaque. $T_m = 165°C$, $T_b = 0°C$ (!), properties similar to PE, higher temperature resistance, higher crazing resistance, lower impact strength.

Specialty grades:

Copolymers with PE, improved impact strength.

PP-elastomer blends with EPM and EPDM.

Important processing techniques: Injection molding ($T_P = 170$-$300°C$, $T_c = 20$-$100°C$, $s = 0{,}8$-2%). extrusion (short compression screw), blow moldinp, thermoforming, machining, welding (heat element, friction), bonding only with surface treatment (see PE).

1.3.3.Styrene Polymers

1.3.3.1.Components:

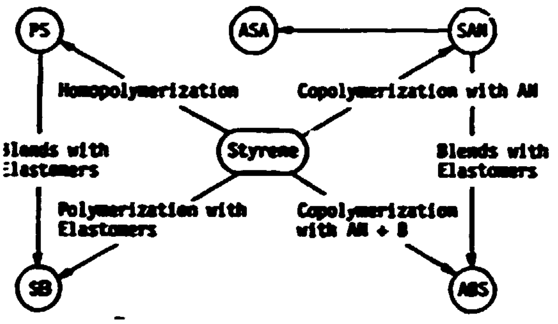
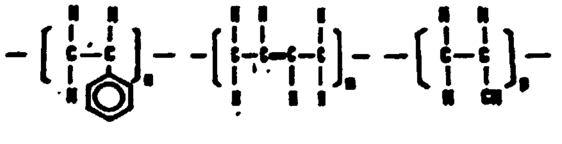


Fig.1.7. Chemical relationship of styrene polymers



PS (homopolymer) = -S-S-S-S-S-S-S-S-S-S-
BS (copolymer) = -S-S-S-B-B-B-B-S-S-S-
BS (polyblend) = -B-B-B-B-B) (S-S-S-S-
ABS (copolymer) = -A-A-A-B-B-B-B-S-S-S-
SAN (copolymer) = -A-A-A-S-S-S-S-A-A-A-

1.3.3.2.Polystyrenes (PS)

Standardization: ISO 1622-80

Significant properties: Density 1,05 g/cm^3, amorphous, transparent, $T_g = 80°C$. Clear, glossy surface, high stiffness, good dimensional stability, good electrical insulation properties, very low impact strength, UV-degradability, brittle fracture, limited chemical resistance, crazing.

Important processing techniques: Injection molding ($T_P = 180$-$250°C$, $T_c = 30$-$60°C$, $s = 0{,}3$-$0{,}7\%$), extrusion, thermoforming bonding, welding, foaming (EPS).

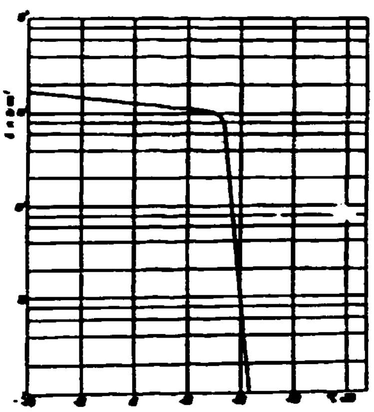


Fig.1.8. G-T-function of PS

1.3.3.3.Styrene-Butadienes (SB, BS)

Standardization: ISO 2897 (polyblend, copolymer)

Significant properties: Density 1,04 g/cm^3, amorphous, normally not transparent, $T_g = 85°C$, good dimensional stability, good electrical insulation properties, good impact strength.

Important processing techniques: Injection molding ($T_P = 180$-$250°C$, $T_c = 20$-$70°C$, $s = 0{,}4$-$0{,}7\%$), extrusion, thermoforming, welding, bonding, machining.

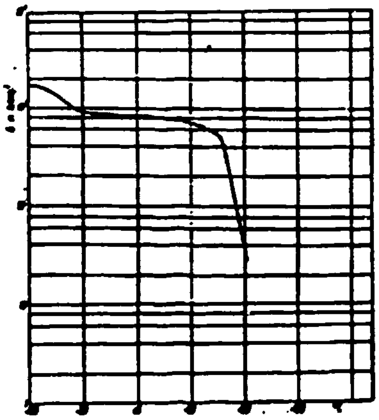


Fig.1.9. G-T-function of SP (BS)

1.3.3.4.Styrene-Acrylonitrile-Copolymers (SAN)

Standardization: ISO 4894

Significant properties: Density 1,08 g/cm^3, amorphous, transparent, clear, $T_g = 85°$ C, high hardness, high stiffness, fair impact strenght, good electrical properties, high gloss.

Important processing techniques: Injection molding (T_P = 200-260°C, T_c = 40-80°C, s = 0,5-0,6%), extrusion, blow molding, thermoforming (130°C), welding, bonding, machining.

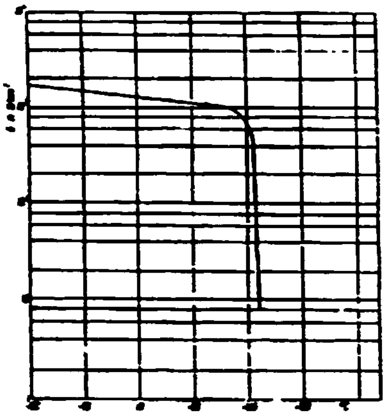


Fig.3.10. G-T-function of SAN

1.3.3.5.Acrylonitrile-Butadien-Styrene-Polymers (ABS)

Standardization: ISO 2580 (polyblends, copolymers)

Significant properties: Density 1,03-1,07 g/cm^3, amorphous, normally not transparent, high impact strength also at low temperatures (up to -40°C) good thermal resistance, low gloss.

Important processing techniques: Pre-drying recommended, injecti on molding (T_P = 200-270°C, T_c = 40-85°C, s = 0,4-0,7%), extrusion, blow molding, thermoforming (140-170°C), bonding, welding, drawing (stamping), machining, galvanizing.

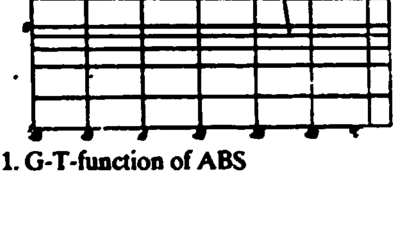


Fig.1.11. G-T-function of ABS

1.3.3.6.SAN-Acrylic Ester Modification (ASA)

Significant properties: Density 1,07 g/cm^3, amorphous, not trans parent, extremely high impact strength, good crazing resistance, good weathering behavior.

Important processing techniques: Pre-drying (2h at 80°C), injection molding (T_P = 200-250°C, T_c = 50-80°C, s = 0,4- 0,7%), extrusion, blow molding, thermoforming (140-170°C), bonding, welding, machining, stamping.

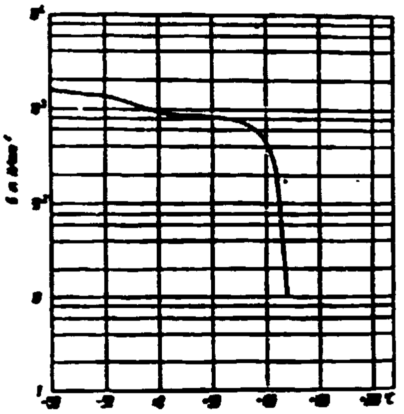


Fig.1.12 G-T-function of ASA

1.3.3.7.Styrene-Maleic Anhydride (SMA)

(Polyblends, terpolymers)

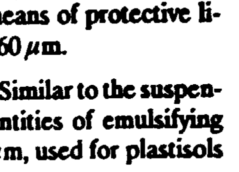
Significant properties: amorphous, not transparent, major characteristic compared with ABS or SAN is the improved heat resistance up to 120°C, good creep resistance.

Important processing technique: Pre-drying (2h at 100°C), injection molding (T_P = 230-265°C, s = 0,4-0,6%), extrusion, blow molding, thermoforming, bonding, welding.

1.3.4. Vinylchloride Polymers

1.3.4.1.Unplasticized Polyvinylchlorides (PVC-U)

Standardization:



$$-\left[\begin{array}{c}H\ \ H\\ |\ \ \ |\\ C-C\\ |\ \ \ |\\ H\ \ Cl\end{array}\right]_n-$$

ISO 1060 (PVC)
ISO 1163 (PVC-U)

Polymerisation:

PVC-S (Suspension, 83%): VC droplets are suspended in water by means of protective liquids, particle size 100-160 μm.

PVC-E (Emulsion, 8%): Similar to the suspension process, larger quantities of emulsifying agents, particle size 0,5 μm, used for plastisols and organosols.

PVC-M (Mass, 7%): VC is polymerized in the absence of any other medium, pure material, particle size about 100 μm.

PVC-L (Solution, 2%): VC is dissolved, used for specialty grades (film forming properties).

Significant properties: Density 1,38-1,41 g/cm^3, (1,55 g/cm^3 PVCC), mainly amorphous, T_g = 85°C, polar, clear (PVC-S, PVC-M), opaque (PVC-E), high stiffness, high tensile strength, good electrical properties (PVC-S, PVC-M), not used in HF engineering, impact resistance depending on modification, good crazing resistance depending on modification, good barrier properties, VC-monomers toxic, HCl corrosive.

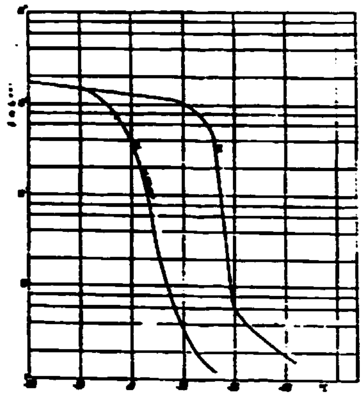


Fig.1.13 G-T-function of PVC

Specialty grades:

- VCVAC (VC-vinylacetate copolymers): higher toughness, improved fluidity.
- VCVDC (VC-vinylidenchloride copolymers): higher temperature resistance.
- PVCC (chlorinated PVC): higher temperature resistance, higher chemical resistance, lower fluidity.
- Modified PVC (with CPE, ACR, EVA modifiers): improved impact strength.

Important processing techniques: Compounding, extrusion (T_P = 170- 190°C, high viscosity, thermal stability), calandering, blow molding, thermoforming (110-180°C), bonding, welding (HF!), machining, injection molding difficult (PVC-S, low K-value, T_P = 170-210°C, T_c = 30-60°C, s = 0,2-0,5%).

1.3.4.2.Plasticized Polyvinylchlorides (PVC-P)

Standardization: ISO 2898, 4612

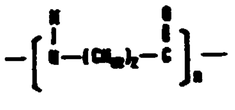
Significant properties: Density 1,20-1,35 g/cm^3, amorphous, polar, clear. Mechanical properties are determinded by the plasticizer and filler content, high flexibility, reduced mechanical and chemical properties, only selected plasticizers food proof, no crazing because of relaxation, brittleness after plasticizer migration.

Important processing techniques: Extrusion (PVC-E, PVC-S, T_P = 150-200°C), calendering, injection molding (PVC-S, PVC-M, T_P = 170-200°C, T_c = 20-60°C, s = 1,0-1,5%), bonding (THF, migration), welding (HF), casting, dipping, sintering, coating (plastisols).

1.4.Engineering Thermoplastics

1.4.1.Polyamides (PA)

Standardization: ISO R 1874



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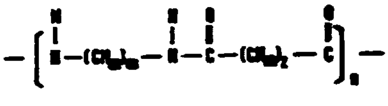

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Significant properties:

Material	Structure	Density (g/cm³)	Water absorption (20°C)(%)	Melt temperature T_m (°C)
PA 6	cryst.	1,12-1,14	8,5-11	215-225
PA 66	cryst.	1,13-1,14	7,5-10	250-265
PA 610	cryst.	1,06-1,08	3-4	210-225
PA 612	cryst.	1,04-1,06	2-3	200-210
PA 11	cryst.	1,04	1,8-2,2	180-190
PA 12	cryst.	1,01-1,02	1,5-1,8	175-185
PA 6-3-T	amorph.	1,06-1,08	6,5	-

Crystalline materials are opaque, amorphous are transparent. Mechanical and electrical properties depend on PA-type, crystal linity (up tot 60%) and water content. High crystallinity: high stiffness, high water content: high impact strength, excellent frictional properties, good chemical resistance, UV-degradation.

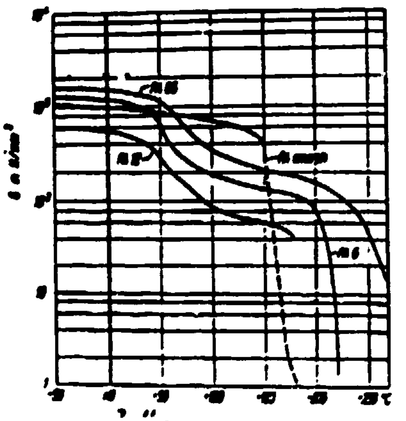


Fig.1.14. G-T-function of PA

Property	Water content ↑	Crystallinity ↑
Tensile strength	↓	↑
E-modulus	↓	↑
Impact strength	↑	↓
Elongation	↑	↓
Electrical resistance	↓	–
Chemical resistance	–	↑
Transparency	–	↓

Fig.1.15. Properties of PA depending on water content and cry stallinity

Important processing techniques: Pre-drying (vacuum, 80°C), injection molding (extremely low viscosity, T_p = 210-290°C, T_c = 30-120°C, s = 1-2%, annealing at 120-150°C), conditioning (constant water content), extrusion (for high molecular types only), bonding, welding, screwing, machining, sintering, casting, (PA 6 G, PA 12 G, liquid monomers).

1.4.2.Linear Polyesters

1.4.2.1.Components

Effects of backbone structure on the melting temperature of polyesters derived from ethylene glycol are shown in Fig.1.16. All linear polyesters show a low rate of crystallization. They can be quenched rapidly into an amorphous state.

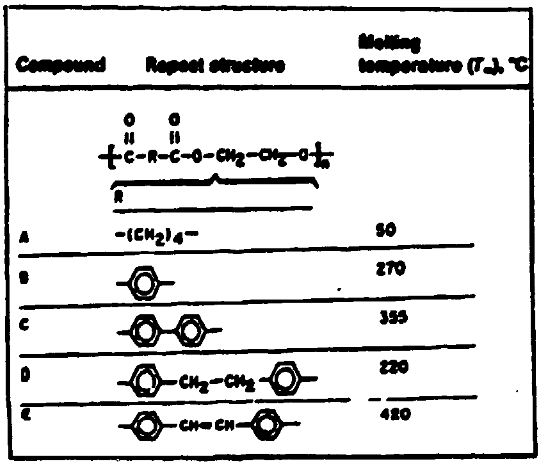
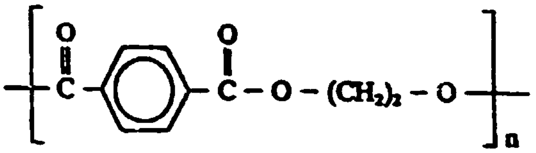


Fig.1.16. Structures and melting temperatures of linear Polyesters

1.4.2.2.Polyethylene terephthalates (PETP)



Significant properties: Density 1,33-1,37 g/cm^3, amorphous to crystalline (up to 40%), T_m = 255-258°C, transparent to opaque depending on cooling conditions, higher crystallinity with nucleiating agents, good abrasive resistance and good frictional behavior, good combination of stiffness with impact strength up to -40°C, good barriere properties, risk of hydrolytic degradation in hot water, no crazing observed.

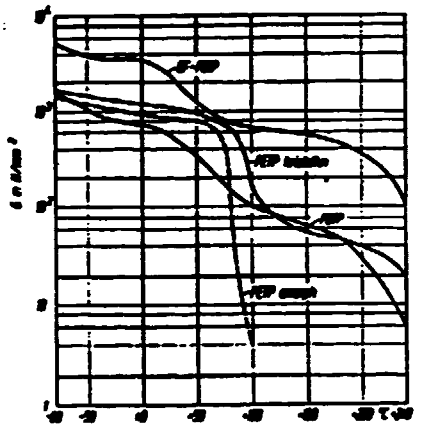


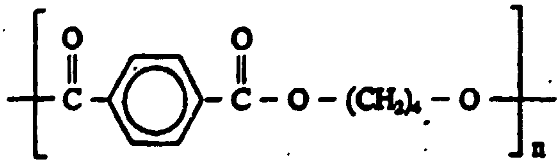
Fig.1.17.G-T-function of PETP and PBTP

Specialty grades:
PCT (polycyclohexane-terephthalate-copolymer): amorphous, used for blisters, packaging material for meat and poultry foods.
PETG is a glycol-modified PET: amorphous, clear, used for chair backs, instrument covers.

Important processing techniques:

Pre-drying (3-4h, 75-90°C), injection molding (T_p = 260-290°C, T_c = 30-140°C, s = 1-2%, thermal stability!), extrusion (stretch) blow molding, thermoforming (225°C), bonding, welding, machining (polishing to high gloss).

1.4.2.3.Polybutyleneterephthalats (PBTP)

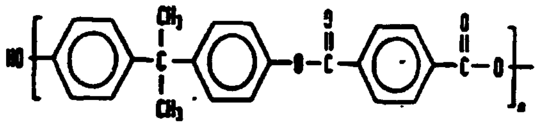


Significant properties: Density 1,29 g/cm^3, crystalline, T_m = 220-225°C, opaque/white, similar to PETP with reduced mechanical properties, excellent processibility, good impact strength also at low temperatures, excellent friction behavior, good thermal resistance up to 110°C. Good electrical properties, risk of hydrolytic degradation, no crazing observed.

Specialty grades:
Polyblends with PETB and PC.

Important processing techniques: Pre-drying (3-4h, 75-90°C), injection molding ($T_p = 230$-$270°C$, $T_c = 30$-$60°C$, s = 1-1,5%, low viscosity, thermal degradation), extrusion, blow molding, thermoforming (225°C), bonding, welding, machining, similar PETP.

1.4.2.4.Polyarylates (PAR)

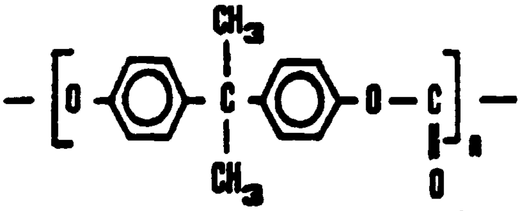


Significant properties: Density 1,21 g/cm^3, amorphous, $T_g = 180°C$, transparent, combination of high modulus, flexural recovery, high heat deflection temperature, good electrical properties, risk of hydrolytic degradation, no crazing.

Specialty grades:
Aromatic homopolyesters: high temperature resistance.
Polyblends with PC and PSU.

Important processing techniques: Pre-drying (4-7h, 120-150°C), injection molding ($T_p = 320$-$370°C$, $T_c = 120$-$150°C$, s = 0,2-0,9%), extrusion, blow molding, bonding, machining.

1.4.3.Polycarbonates (PC)



Significant properties: Density 1,20-1,24 g/cm^3, mainly amorphous, transparent, glossy, extremely high impact strength, good temperature resistance, risk of hydrolytic degradation, crazing,

Specialty grades:
Copolymers and polyblends with ABS, PBTP.

Important processing techniques: Pre-drying (4h, 120-130°C), injection molding ($T_p = 280$-$320°C$, $T_c = 80$-120 °C, s = 0,7- 0,8%), extrusion, thermoforming (180-220°C), bonding, welding (400°C), annealing (30 min, 120°C) finishing.

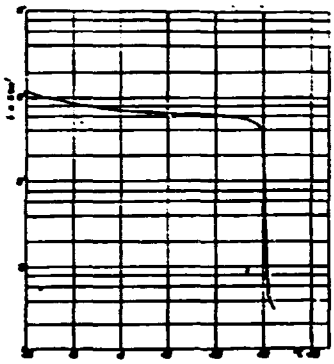
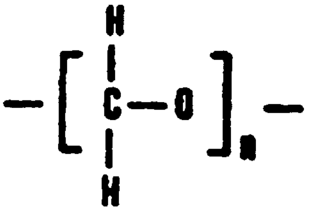


Fig.1.18. G-T-function of PC

1.4.4.Polyacetales (POM)



$$-\left[\overset{H}{\underset{H}{C}}-O\right]_n-$$

Polyformaldehyde, Polyoxmethylene

Significant properties: Density 1,41-1,43 g/cm^3, high crystallinity (up to 75%) $T_m = 175°C$ (for copolymers 165-168°C), opaque. Highest elasticity modulus for engineering materials (up to 3500 N/mm^2), good abrasion and frictional behavior, high impact strength up to -40°C, no water absorption, good crazing resistance.

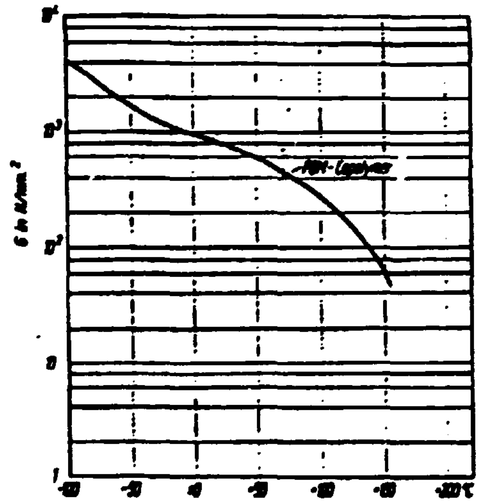
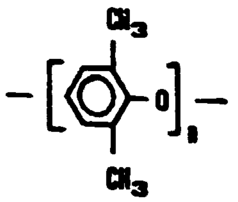


Fig.1.19. G-T-function of POM

Specialty grades:
PEOX (Copolymers with polyethyleneoxid)

Important processing techniques: Injection molding ($T_p = 180$-$320°C$, $T_c = 50$-$120°C$, s = 1,0-3,5%, decomposition at 240°C!), extrusion, blow molding, thermoforming (160-170°C), annealing (110-140°C), bonding difficult, welding, machining, screwing, snaping, finishing (surface treatment).

1.4.5. Polyethylene oxides (PPO)



Significant properties: Densitiy 1,06-1,10 g/cm^3, through modification with PS amorphous (polyblend), not transparent, high dimensional stability, best creep behavior, good abrasive resistance, good electrical behavior, crazing with carbonhydrogenes, low flammability.

Important processing techniques: Pre-drying recommended (2h, 80- 120°C), injection molding (T_p = 260-300°C, T_c = 80-110°C, s = 0,5-0,7%, high injection speed), extrusion (gasing screw), blow molding, thermoforming, bonding, welding (290°C), screwing, machining, foaming (structural foam).

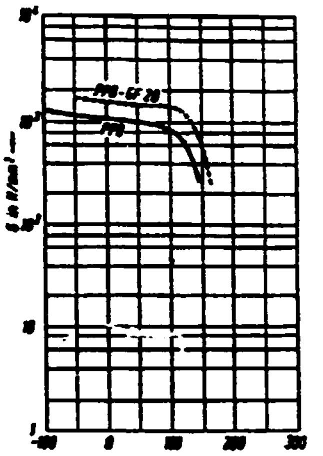
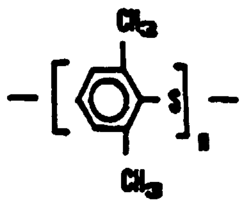


Fig.1.20. G-T-function of PPO

1.4.6.Polyphenylene sulfides (PPS)



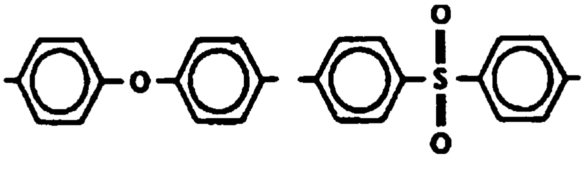
Significant properties: Density 1,34 g/cm^3, crystalline, unpolar, T_m = 280-288°C, brown, high tensile strength, high elasticity modulus, very good creep behavior, very good temperature resistance, low impact strength (depending on crystallinity), no crazing observed.

Important processing techniques: Pre-drying (150-170°C), injection molding (T_p = 300-360°C, T_c = 20-200°C, s = 0,7%), compression molding (crosslinking under oxygen at 370°C), bonding, welding (US), machining, sintering.

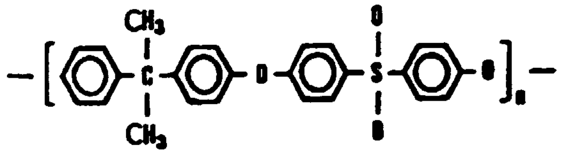
1.4.7. Sulfone Polymers

1.4.7.1.Components

The inherent oxidative and thermal stability of the sulfone polymers is due to the diarylsulfone group and the diphenylether group.



1.4.7.2.Polysulfone (PSU)



Significant properties: Density 1,24 g/cm^3, amorphous, transparent yellow, excellent thermal stability (-100 to + 180 °C), good creep behavior also at 180°C, inflammability, crazing in some agents.

Important processing techniques: Pre-drying (4h, 135-150°C), injection molding (T_p = 310-390°C, T_c = 95-115°C, s = 0,7- 0,8%, release agent prohibited), extrusion, blow molding, thermoforming (200°C), bonding, welding (US), screwing, machining (polishing), galvanizing.

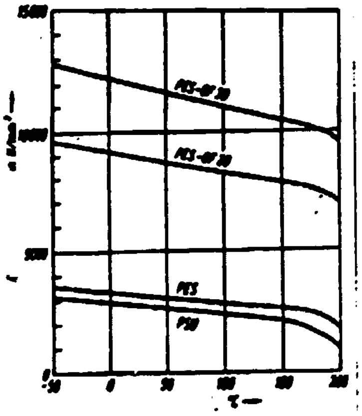
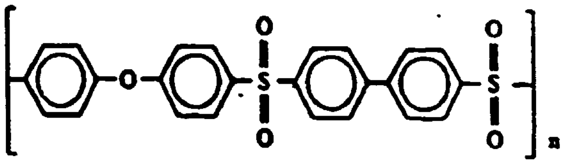


Fig.1.21 G-T-function of PSU and PES

1.4.7.3.Polyphenylsulfone (PPSU)

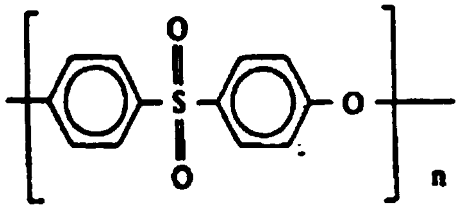


Polyarylsulfone

Significant properties: Density 1,36 g/cm^3, amorphous, transparent yellow, unpolar, excellent thermal stability (-100 to 260°C), excellent creep behavior, inflammability.

Important processing techniques: Pre-drying (4h, 135-150°C), injection molding (T_p=390-430°C, T^c=170-260°C, s=0,7%, release agent prohibited), annealing (5h, 165°C), extrusion, blow molding, thermoforming (220°C), bonding, welding (US), screwing, machining (polishing), galvanizing.

1.4.7.4.Polyethersulfone (PES)



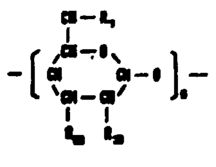
Significant properties: Density 1,37 g/cm^3, amorphous, transparent yellow, unpolar excellent thermal stability (-100 to 200°C), excellent creep behavior, inflammability.

Important processing techniques: Pre-drying (4h, 135-150°C), injection molding (T_p=340-390°C, T_c=120-160°C, s=0,6%, release agent prohibited), annealing (5h, 160°C) extrusion, blow molding, thermoforming (200°C), bonding, welding (US), screwing, machining (polishing), galvanizing.

1.5.Specialty Thermoplastics

1.5.1.Cellulosics

Esterification of cellulose with acetic acid (CA), butyric acid (CB), propionic acid (CP) and co-esters (CAB).



R_1, R_2, R_3 substitutions:
CA: CH_3COO —
CP: $CH_3(CH_2)_nCOO$ —
CAB.

Significant properties: amorphous, transparent, clear good electrostatic behavior, good crazing resistance, high gas permeability.

Material	Density (g/cm^3)	Plasticizer content (%)	Water absorption(%)
CA	1,26-1,32	20-30	2,8-4,6
CAB	1,16-1,22	3-15	1,7-2,4
CP	1,19-1,23	10-20	1,8-2,8

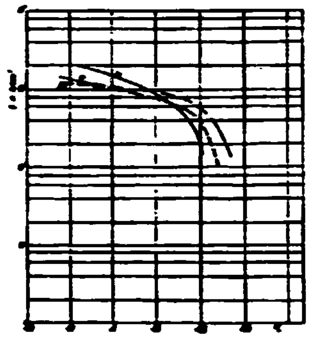
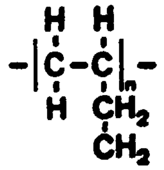


Fig.1.22. G-T-function of CA, CAB, CP

Important processing techniques: Pre-drying (3h, 80°C), injection molding (T_p=180-230°C, T_c=40-70°C, s=0,2- 0,7%), conditioning (24h, 20°C), extrusion, blow molding, thermoforming, bonding (solvent), welding, casting, sintering.

1.5.2.Specialty Polyolefines

1.5.2.1.Polybutene (PB)

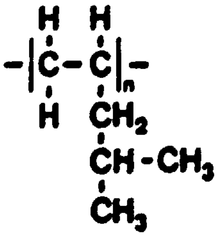


$$-\left[\begin{array}{cc} H & H \\ | & | \\ C - & C \\ | & | \\ H & CH_2 \\ & | \\ & CH_3 \end{array}\right]_n-$$

Significant properties: Density 0,91-0,92 g/cm^3 (I), crystalline (up to 50%) opaque T_m=120-130°C (form I), 115-120°C (form II), 98-103°C (form III). Crystallization from the melt leads to the metastable form II, the latter transformations irreversible to the stable form I over 5-7 days (end use), mechanical properties similar to PP, better crazing resistance.

Important processing techniques: Injection molding (T_p=190-230°C, T_c=40°C, s=1,5-2,5%), extrusion, blow molding, welding.

1.5.2.2.Polymethylpentene (PMP)

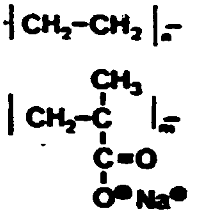


$$-\left[\begin{array}{cc} H & H \\ | & | \\ C - & C \\ | & | \\ H & CH_2 \\ & | \\ & CH-CH_3 \\ & | \\ & CH_3 \end{array}\right]_n-$$

Significant properties: Density 0,83 g/cm^3, crystalline, transparent (!), T_m=240°C, very good dielectric behavior, sterilizable (120°C), low impact strength, crazing.

Important processing techniques: Injection molding ($T_p = 260\text{-}320°C$, $T_c = 20\text{-}60°C$, $s = 1,5\text{-}2\%$), blow molding, welding.

1.5.2.3.Ionomer

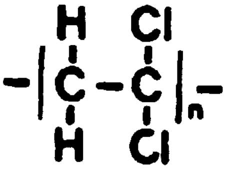


Ionomers contain interchain ionic bonding based on Na-or Zn-salts of ethylene/metacrylic acid copolymers.

Significant properties:
Density 0,94-0,96 g/cm^3, ionic crosslinking between -40 to +40°C, transparent, good mechanical inertness, high tensile strength compared with PE, low dielectric loss, excellent crazing resistance.

Important processing techniques: Injection molding ($T_p = 290\text{-}330°C$, $T_c = 20\text{-}40°C$, $s = 0,7\text{-}1,9\%$), extrusion, blow molding, welding.

1.5.3.Vinylidenchloride Polymers

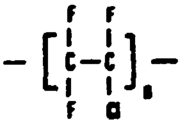


PVDC: Polyvinylidenchloride
Significant properties: amorphous, transparent, clear, good mechanical properties, very good barriere properties against water vapor and oxygen.

Important processing techniques: Extrusion ($T_p = 200\text{-}210°C$, decomposition at 210°C), solution coating.

1.5.4.Thermoplastic Fluorpolymers

PCTFE:Polychlorotrifluorethylenes

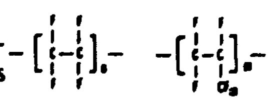


ECTFE:Ethylene-chlorotrifluoroethylene copolymers

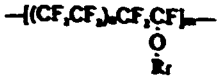
$-(\mathrm{CH_2CH_2CF_2}\underset{\mathrm{Cl}}{\mathrm{CF}})_n-$

ETFE:Ehtylene-tetrafluorethylene copolymers $-(\mathrm{CH_2CH_2CF_2CF_2})_n-$

FEP:Fluorinated ethylene-propylene copolymers

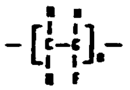


PFA:Perfluoroalkoxy copolymers

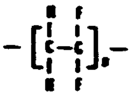


$-[(\mathrm{CF_2CF_2})_n\mathrm{CF_2}\underset{\underset{\mathrm{R_f}}{\mathrm{O}}}{\mathrm{CF}}]_m-$

PVF:Polyvinylfluorides



PVDF:Polyvinylidenfluorides



Significant properties: Crystalline, opaque, white, combination of very high chemical resistance, very high temperature resistance, good mechanical properties, low wettability and useful electrical properties, excellent friction behavior.

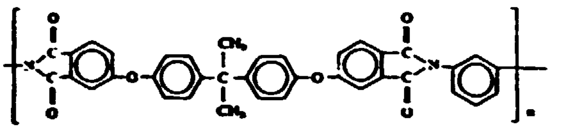
Material	Polarity	Density (g/cm^3)	Brittleness temperature (°C)
PCTFE	polar	2,1	-100
ECTFE	polar	1,7	-100
ETFE	unpolar	1,7-1,8	-100
FEP	unpolar	2,1-2,2	-100
PFA	unpolar	2,1-2,2	-200
PVF	polar	1,4-1,6	-70
PVDF	polar	1,75	-60

Important processing techniques and typical applications: Injec tion molding, blow molding, extrusion, compression molding, welding, machining. Use of corrosion resistant materials on any equipment required.

Material	Processing temperatur T_p(°C)	Shrinkage (%)
PCTFE	260-320	1,0-1,5
ECTFE	260-300	2,0-2,5
ETFE	280-330	2,0-2,5
FEP	330-420	3,0-6,0
PFA	350-420	4,0
PVF	220-320	2,0-4,0
PVDF	220-300	3,0

1.5.5.Thermoplastic polyimides (PI)

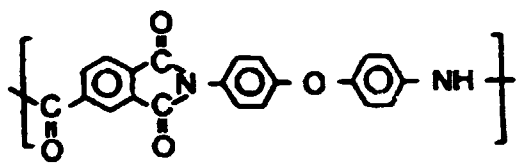
1.5.5.1.Polyetherimides



Significant properties: Density 1,3-1,4 g/cm³, amorphous, polar, dark, excellent temperature resistance, good mechanical properties, low impact strength, good frictional behavior up to 200°C, insufficiant weather resistance.

Important processing techniques: Pre-drying (4h, 150°C), injection molding (T_P=340-430°C, T_C=100-150°C, s=0,5-0,7%), compression molding (T_P=220-360°C, p=100-300 bar, annealing 24h at 250°C), casting (from solution), machining, foaming.

1.5.5.2.Polyamide-imides



Significant properties: Good mechanical properties, creep resistance from -200 to 260°C, good electrical behavior, relatively high water absorption.

Important processing techniques: Injection molding (T_P=300-400°C).

1.5.6.Thermoplastic Elastomers (TPE)

Thermoplastic elastomers are a diverse family of rubberlike but not crosslinked materials that can be processed and recycled as thermoplastics.

Linear polyurethanes (PUR)
Copolyesters (typically PBTP and polytetramethylene ether glycol)
Styrene block copolymers (PS and polyisoprene, polybutadiene, EPR)
Polyolefine blends (PE and EPR)
Ionic elastomers
Polyether-polyamide elastomers

Significant properties: Structure of blocks or domains of hard thermoplastic constituents link elastomeric constituents in a network that behaves at service temperature like a chemically crosslinked structure. At processing temperatures the hard domains soften and allow the polymer to flow. High toughness, flexibility over a wide range of temperature, good resistance to abrasion and weathering.

Important processing techniques: Injection molding, compression molding, extrusion, reaction injection molding (RIM), casting.

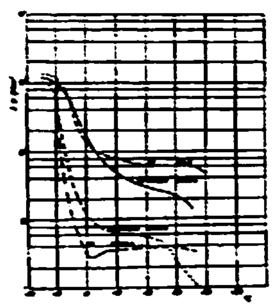
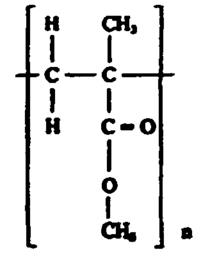


Fig.1.23 G-T-function of PUR elastomers

1.6.Thermoelastics

1.6.1. Acrylics

Acrylics include homopolymers, copolymers and monomers. The most important is PMMA: polymethyl methacrylate



Specialty grades:

AMMA: Acrylonitril-MMA-co-polymers

MBS: MMA and butadiene-styrene-co polymers

Significant properties: Density 1.18 g/cm³, (PMMA), 1,17 (AMMA), 1,08 (MBS), amorphous, brilliant, transparent, glossy, excellent aging behavior, high stiffness, low water absorption.

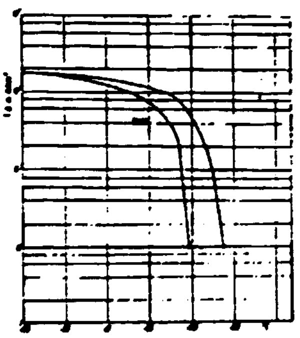


Fig.1.24. G-T-function of PMMA

Important processing techniques: Casting, pre-drying (4h, 70-100°C), injection moulding (Tp=200-250°C, Tc=50-90°C, s=0,3-0,8%), extrusion, thermoforming (150-180°C), annealing (2-3h, 60-80°C), bonding, welding, machining.

2.Extrusion of Blown Films

2.1. Introduction

Film blowing is the most important method for producing polyethylene films. It is estimated that some 90% of all PE films are produced on blowing lines. The extrusion process offers optimum efficiency and other advantages, like variability in the width and thickness dimensions, and the outstanding mechanical proper ties obtainable by biaxial orientation.

Machinery development went through a build-up phase under pressure from the efforts to raise the quantity and quality of the end product in order to satisfy increasing demands. Thuss, by comparison with 1955, it has been possible to raise the output of medium-sized extrusion units by about a factor of two or three. In spite of the large increase in machine costs that also took place over this period, it was possible to reduce the price/output ratio of a blown film line, and so investment- and operational unit costs are more favorable with modern, high- performance lines than with older ones. Using more precise market intelligence it has been possible to establish that the demand some years ago for quantitative improvement in performance yielded an increasing quality consciousness. This can be recognized in the fact that use of coextrusion to manufacture superior multilayer films shows a disproportionately high growth rate, and test equipment for quality control is being increasingly used. The move towards high-quality film is also based on the demand to be able to produce the ideal film for a given purpose. Thus the usual range of film properties, like dimensional precision, strength, extension at break, shrinkage, weldability, conversion efficiency ("machinability"), among others, broadened to include additional quality characteristics relevant to the end use, such as gas barrier, moisture barriere, chemical resistance and so on.

The characterization of a film or a film composite must take conversion operations and end uses into account. There are many criteria and test methods used for quality characterization of blown films.

Dimension control

Film thickness. The thickness variation along and across the machine running direction is a particularly important quality criterion which strongly influences secondary processability and the way the material can be used.

The variations in longitudinal thickness should be less than +/- 2% from the average. In the transverse direction, depending on film thickness, low-up ratio, material, and film speed, the variation can be +/- 3% to +/-15%.

Film width. Maintenance of narrow width tolerances is achieved by the use of calibration and control system. The width tolerance achieved with a modern high-performance lies between +/-1 and +/- 2mm.

Machine running

Machine running characteristics serve as a measure of the convertibility of films. They are determined by dimensional accuracy, stiffness, frictional and slip behavior, tendency to sticking (blocking flatness) and other properties. Assessment of machinability is carried out almost exclusively by experiment, or is based on experience. Machine running characteristics can be influenced by appropiate adjustment of the operational parameters or by modification of the raw material employed.

The stiffness of the film is very important in relation to transfer and conveying devices on packaging equipment, sack- and bag- machines.

By blocking is meant the situation when layers of film stick to one another. It is caused by the film being too hot when it is squeezed by the haul-off unit and at the wind-up station, or because of deficiences in the material itself. During extrusion, low-molecular-weight olefinic compounds migrate to the surface of the film, where they can lead to blocking. By use of an internal air exchange system these compounds are extracted from inside the bubble, and the tendency to blocking is reduced.

Optical quality criteria

Air as cooling medium offer a cost-effective means of energy removal, but has the disadvantage that it cools the film down slowly and the surface becomes rougheded by air turbulence. The kind of clarity that is possible with the chill-roll process cannot be obtained with blown film.

For characterization of the optical properties the most imoportant methods are

- gloss measurement	(ASTM D 2457),
- measurement of the reflection and scattering effect at the film surface, haze measurement	(ASTM D 1003),
- passing a beam of white light through the film, measurement of "see-through" clarity	(ASTM D 1746),

- measurement of the sharpness of an image viewed through the film.

For optical and quality characterization of a film, a count of gel particles and impurities is also used.

Strength, extension, shrinkage

The following well-known test methods are used:

- tensile test (stress at break, extension at break)	DIN 53 455 ISO R/1184 ASTM 882-67
- tear propagation resistanceon trapezoidal, and on Graves'angle test specimens	DIN 53 363 DIN 53 515
- edge test resistance	DIN 40 634
- puncture test (energy, force to damage)	DIN 53 373
- dart drop test	ASTM D 1709-62 T

There are no standard test for measuring shrinkage and shrinkage forces. But one widely adopted method for determining the shrinkage is to observe dimensional changes in a film specimen 15 mm wide, 100 mm long, after 20 s immersion in a glycerine/water mixture at 120°C.

The determination of shrinkage requires a much greater effort and is therefore usually only carried out in larger laboratories.

2.2.PE-LD Blown Film Lines

2.2.1.Elements

Blown film lines consist essentially of five elements.

- extruder,
- die unit,
- cooling and calibration unit,
- haul-off unit,
- wind-up.

2.2.2.Extruders

Extruders used for LDPE blown film production are predominantly slow-running single-screw units, with the following range of dimensions:

- screw diameter D: 40 to 200 mm,
- screw length: 20 D to 30 D.

The speed of these extruder screws is limited to a maximum surface velocity of 0.8 to 1.2 m/s.

High-performance extruders for blown film have very efficient, sleeved feed zones, which have the following features (Fig.2.1.)

- lengthwise grooves which taper concially in the transport direction,
- intensive cooling of the grooved sleeve,
- good heat barrier between the heated barrel and the grooved sleeve,
- relatively small screw-flight depth.

The operating principle, in brief, is as follows:
the lengthwise grooves and the shallow screw channels produce stable granule bridges which receive a strong component of shear in the transport direction from the screw flights, since the grooves inhibit rotational motion of the granulate. Intensive cooling and heat insulation is needed to suppress premature plastication.

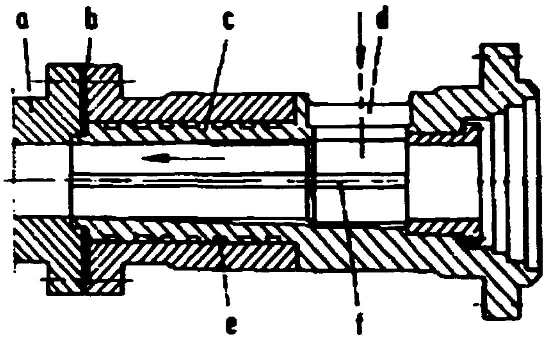


Fig.2.1. High efficiency feed zone (a) extruder barrel, (b) thermal break, (c) grooved sleeve, (d) feed opening, (e) cooling spiral, (f) grooves.

This extrusion principle makes it possible to operate with low extrusion temperatures and, in addition, the transport rate is independent of the back pressure over a wide range. The extruder screw is subdivided into the following functional areas:

- feed and compression,
- plastication with the aid of shear elements,
- homogenization zone with mixing elements.

The screw geometry must be designed so that the melt is processed and mechanically homogenized at the lowest possible temperature.

Materials used for screw are principally chrome steels and nitrided steel with nitridehardened surfaces. The screw lights are usually protected with a wear-resistant alloy, to provide a longer service life particularly for the processing of highly pigmented color concentrates.

2.2.3. Dies

The film blowing head, the die on a blown film line, shapes the melt in a narrow annular gap. This shaping process must be carried out free of blemishes and at the lowest acceptable temperature.

Three kinds of blowing head, in particular, are used industrially

- side-fed dies
- spider-type dies (Fig.2.2.)
- spiral mandrel dies (Fig.2.3.)

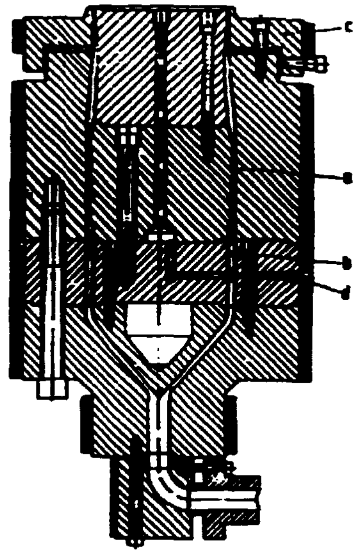


Fig.2.2. Spider-type die (a) smear device, (b) spider ring, (c) centering, (d) entry for internal air

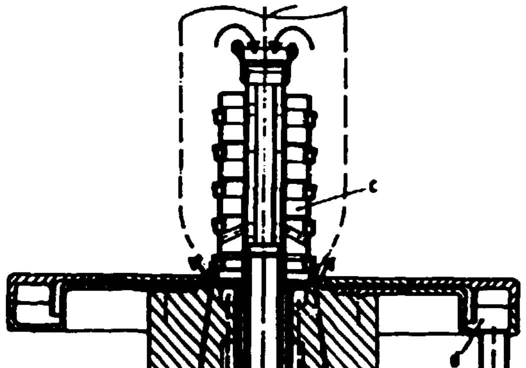


Fig.2.3. Centrally fed spiral mandrel blowing die with internal cooling (Windmöller und Hölscher design). (a) spiral mandrel, (b) centering system, (c) internal cooling system, (d) external cooling

2.2.4. Cooling and calibration

2.2.4.1 External cooling

The melt emerging from the die gap is blown in the thermoplastic state and drawn down to final dimensions. The deformation process stops at the freeze line, which the changeover from the plastic to the solid state occurs.

Bubble cooling is carried out by air emerging from a cooling ring mounted directly on the die outlet. Air volume, air speed, and the direction of the air stream, as well as air temperature, determine the effectiveness of cooling. Cooling rings used nowadays almost without exception employ the labyrinth system of design with single-stage or two-stage pressure equalization chambers.

The cooling ring is judge by three criteria:

- cooling capacity,
- bubble stability,
- uniformity of the airstream.

2.2.4.2 Internal cooling

A significant improvement in performance is achieved with internal cooling by internal air exchange, and this has now become established as a normal feature of high-performance film blowing technology. In Figures 2.4. and 2.5. the influence of cooling air temperature on lines with and without internal cooling is shown schematically.

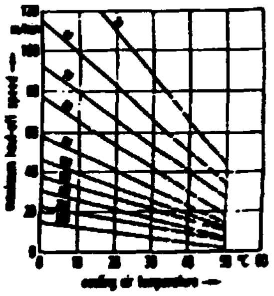


Fig.2.4. Maximum haul-off speed as a function of cooling air temperature and film thickness, without internal cooling (experimental values).

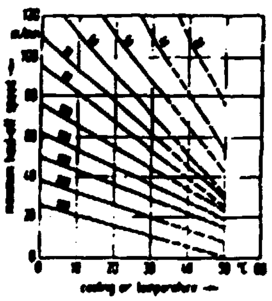


Fig.2.5. Maximum haul-off speed as a function of cooling air temperature and film thickness, with internal cooling (experimental values)

2.2.5.Haul-off unit

Haul-off units include collapsing frames and haul-off or squeeze rolls. Edge guides, also, are extensively used just before the collapsing frames, in order to ensure the stability of the bubble and that the film is fed accurately into the frame.

The collapsing frame is constructed from two ore more wedge-shaped, angularly adjustable surfaces made of either wood or free-running rollers.

The geometrical relationship in collapsing a film bubble are indicated in Figure 2.6. To prevent folds occuring during collapse, one must keep the deformation forces as small as possible, by working with very low friction and the smallest possible opening angle.

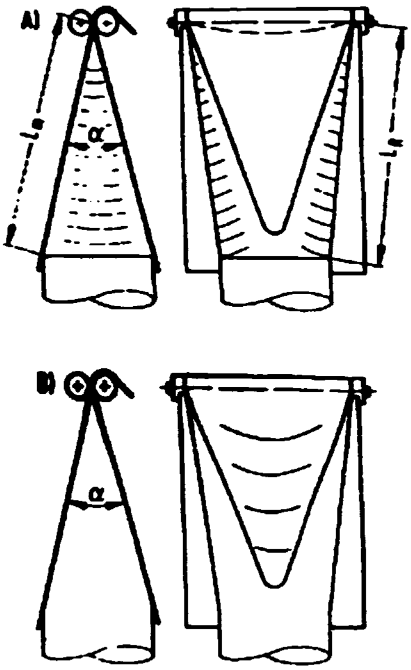


Fig.2.6. Creasing during bubble collapse because of: (A) length difference, (B) frictional resistance

2.2.6.Winders

Film winders are devided into two categories:

- contact winders,
- center-driven winders.

The contact winder (also called circumferential-, surface-, or drive-roll winder) is the type most used on blown film lines.

The rubberized or chromed roll is driven, and the winding shaft or the film-roll is pressed against this roll. Application of roll pressure is achieved mechanically or pneumatically. To obtain good package build-up is important that the axis of the winding shaft lie parallel to that of the contact roll; this is normally ensured by using two coupled support arms along which the film roll is displaced as the diameter increases, with the result that the drive-roll pressure should remain nearly constant (Fig.2.7.)

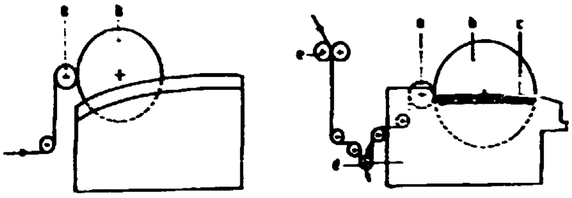


Fig.2.7. Contact winder (schematic) (a) contact roll, (b) film roll, (c) pneumatic cylinder, (d) dancer roll, (e) tensioning rolls

With central winders (also known as axial or direct winders) the winding shaft is direct driven. The drives are designed so that as the film roll diameter increases - and the motor speed decreases - the torque increases to keep the web tension constant. Dancer- roll control (Fig.2.8.) and computer-controlled drives carry out these tasks. Central winders can produce soft rolls of wound film at very low web tension. This process is aided by air that is drawn in between layers during wind-up, and the buffer effect, which compensate film thickness differences. Such rolls are less sensitive to shrinkage after wind-up.

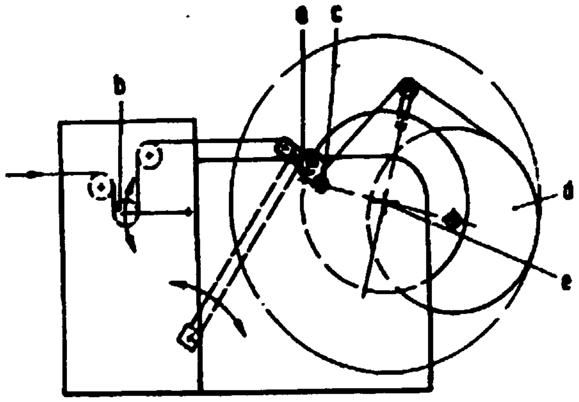


Figure 2.8. Central winder (schematic diagram) (a) swiveling pressure roll, (b) dancer roll, (c) winding shaft in start position, (d) finished roll film, (e) capstan

Winders are usually provided with a range of auxiliary devices:

- guillotines,
- longitudinal slitters
- edge or center control,
- pretreatment,
- edge trim evacuation.

2.2.7. Thickness uniformity

To obtain a cylindrical film roll, the thickness variations occuring in the web must be spread evenly across the full width of the roll, so as to guarantee troublefree conversion. The tubular film process offers various possibilities:

- rotating haul-off/winder combination,
- rotating extruder and die,
- rotating die,
- roating or reversing haul-off elements.

2.3. PE-HD Blown Film Lines

HDPE blown film, also described as high-molecular (HM) film, is much less important than LDPE in the European packaging sector. This is not so in Japan. Yet because of its mechanical properties and special paper-like characteristics it has come to occupy an established place in the film conversion industry.

The property improvements over LDPE, which are briefly described below, result from the particular molecular structure of HDPE:

- high viscosity over the complete range of shear rates,
- tendency to strong flow orientation because of the linear molecular structure,
- moleculare breakdown at high shear rates,
- crosslinking (gel particles) at temperature peaks,
- high melt temperatures,
- post-shrinkage of the film,
- tendency to creasing.

Extruders

HDPE film can equally well be produced on small lines with extruders having short screws of 16 to 25D, and maximum screw surface speeds of 1.4 m/s, as on lines with conventional extruders with special screws. The extruders are equipped with feed zones (grooved sleeves) of high transport efficiency, and screws with shear and mixing zones.

The grooved sleeve operates as a stable solids-conveying pump, and makes possible a high enough specific throughput for the extruder temperature to be kept below 240°C and for thermal breakdown of the material to be avoided.

The high viscosity and surface hardness can lead to increased screw and barrel wear: for this reason hardened steels and hard metal alloys are preferred nowadays for screws and grooved leeves.

Dies

Design calculations on dies have to take pressure of 400 to 800 bar into account. The spiral mandrel die is the best suited to accept high working pressures, because of the design principle followed. The rheological design of the melt channels and spirals has to be carried out in such a way that excessive shear rates are avoided. The use of hard-chromed surfaces is recommended to suppress melt fracture and to avoid build-up of surface deposits (plate-out).

The die diameter generally lies between 30 and 200 mm.

Cooling and calibration

The shape of an HDPE bubble is distinctly different from that of LDPE (Fig.2.9.) Blow-up of the tube occurs, at the earliest, 5 to 8 diameters from the die. The blow-up ratio usually lies between 4:1 and 6:1.

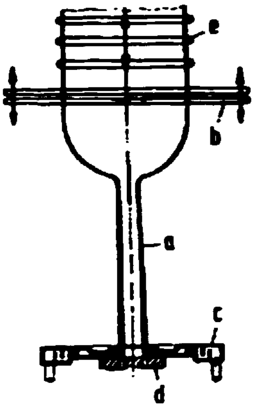


Fig.2.9. Cooling and calibration of HDPE blown film (schematic diagram). (a) bubble neck, (b) iris diaphragm with height adjust ment, (c) cooling ring, (d) blowing head, (e) calibration basket with height adjustment

The cooling ring and the ring-lips are shaped to stabilize the bubble form, as well as to provide intensive cooling. Iris diaphragms with height adjustment, mounted just above the freeze line, are used for calibration.

Haul-off unit

The haul-off unit is fitted with a wood-slat collapsing frame and a large number of side elements to guide the relatively stiff film, and to make it possible to work with a very small angle of opening during collapse of the bubble. To ensure that the film temperature in the collapse region is correct, the haul-off is often adjustable in height.

Winder

In HDPE blown film technology contact winders are used almost exclusively. It is advisable to use tensioning rolls to isolate the wind-up from the high tension of the film web. The auxiliary equipment described in 2.2.5. is also installed on HDPE winders. On compact winders, edge control of the web can be omitted.

Thickness distribution

There are three preferred systems in normal use for spreading out unavoidable thickness variations in the film:

- rotating extruder with die,
- rotating haul-off/winder combination,
- rotating die/cooling ring unit.

Lines with internal air exchange can also be used for producing HDPE film, an·' although no particular improvement in performance is to be expected, there are several advantages worth noting:

- improved bubble stability,
- improved cooling,
- evacuation of volatiles.

2.4.PE-LLD Blown Film Lines

This raw material has displaced LDPE in some application because of its special mechanical properties and the low cost of production (low pressure process). A comparison with LDPE brings out the special features of this material:

- for the same strength a 25 to 50% reduction in film thickness is possible,
- extension at break is about 200% greater.

In the USA about 30% of all LDPE has been replaced by LLDPE, but in Europa LLDPE is only used for stretch films, in refuse sacks, as a second component in LDPE and HDPE, and in coextrusion applications.

The machinery producer has to make modifications to take account of the particular characteristics of this material, which relate especially to the molecular structure and the rheological behavior:

Viscosity: (Fig.2.10.)

The higher viscosity relative to LDPE requires a higher screw torque or drive torque, and modification to the screw geometry, in order to produce the lowest possible melt temperature.

Narrow molecular-weight distribution:

This reduces the strength in the plastic state and lowers bubble stability, and calls for a special cooling technique to be used. The external cooling system has the additional task of supporting and stabilizing the bubble. For this reason two-stage cooling rings are quite often used to produce a Venturi effect (partial vacuum).

Melt fracture:

To counteract melt fracture, which is a coarse deformation of the surface of the extrudate as it emerges from the die, the die gap must be increased (Fig.2.11.)

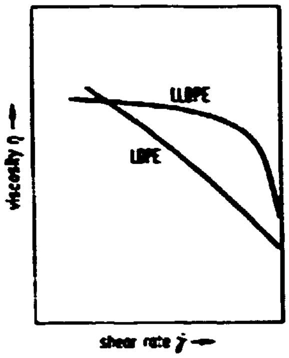


Figure 2.10. Viscosity as a function of shear rate for LDPE and LLDPE (general principles).

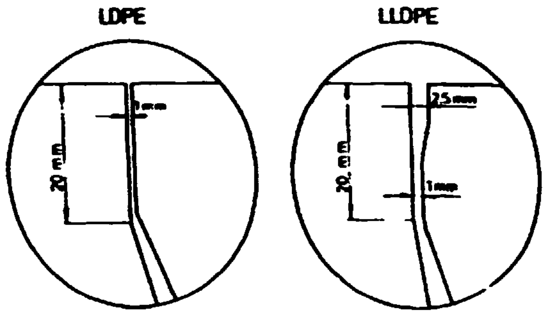
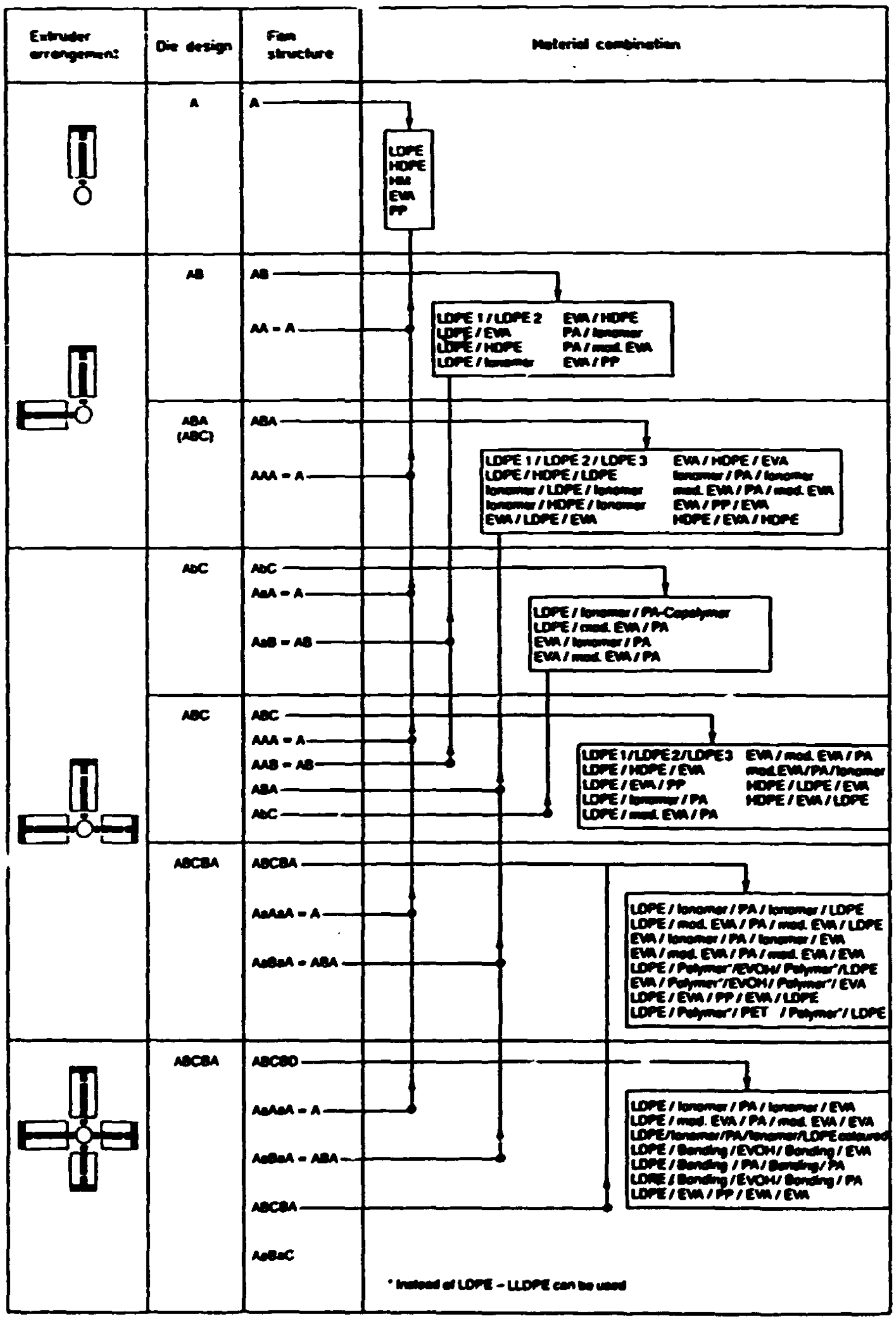


Figure 2.11. Die contours for LDPE and LLDPE with experimental values.

2.5.Blown Film Coextrusion

2.5.1.Process

The sixties saw the development of processes for making multilayer blown films in one operation and their application in the production of LDPE double-layer films. The main field of application was for two-colored milk-pouch film which was dyed white/black or white/brown. At the same time heavy-duty bag films with improved properties were introduced into the market in the USA. As many fields of application, particularly in the food sector, set moisture- and gas-barrier requirements which could no longer be fullfilled by one raw material, the seventies saw the further development or coextrusion of incompatible raw materials such as PA and LDPE as well, the adhesion required was achieved by inserting an adhesive layer by extrusion or by applying gas treatment (Table 2.12.)



Extruder arrangement	Die design	Film structure	Material combination
	A	A	LDPE HDPE HM EVA PP
	AB	AB AA = A	LDPE 1 / LDPE 2 LDPE / EVA LDPE / HDPE LDPE / Ionomer EVA / HDPE PA / Ionomer PA / mod. EVA EVA / PP
	ABA (ABC)	ABA AAA = A	LDPE 1 / LDPE 2 / LDPE 3 LDPE / HDPE / LDPE Ionomer / LDPE / Ionomer Ionomer / HDPE / Ionomer EVA / LDPE / EVA EVA / HDPE / EVA Ionomer / PA / Ionomer mod. EVA / PA / mod. EVA EVA / PP / EVA HDPE / EVA / HDPE
	AbC	AbC AaA = A AaB = AB	LDPE / Ionomer / PA-Copolymer LDPE / mod. EVA / PA EVA / Ionomer / PA EVA / mod. EVA / PA
	ABC	ABC AAA = A AAB = AB ABA AbC	LDPE 1/LDPE 2/LDPE 3 LDPE / HDPE / EVA LDPE / EVA / PP LDPE / Ionomer / PA LDPE / mod. EVA / PA EVA / mod. EVA / PA mod.EVA/PA/Ionomer HDPE / LDPE / EVA HDPE / EVA / LDPE
	ABCBA	ABCBA AaAaA = A AaBaA = ABA	LDPE / Ionomer / PA / Ionomer / LDPE LDPE / mod. EVA / PA / mod. EVA / LDPE EVA / Ionomer / PA / Ionomer / EVA EVA / mod. EVA / PA / mod. EVA / EVA LDPE / Polymer*/EVOH/ Polymer*/LDPE EVA / Polymer*/EVOH / Polymer*/ EVA LDPE / EVA / PP / EVA / LDPE LDPE / Polymer*/ PET / Polymer*/ LDPE
	ABCBA	ABCBD AaAaA = A AaBaA = ABA ABCBA AaBaC	LDPE / Ionomer / PA / Ionomer / EVA LDPE / mod. EVA / PA / mod. EVA / EVA LDPE/Ionomer/PA/Ionomer/LDPE coloured LDPE / Bonding / EVOH / Bonding / EVA LDPE / Bonding / PA / Bonding / PA LDPE / Bonding / EVOH / Bonding / PA LDPE / EVA / PP / EVA / EVA

* Instead of LDPE – LLDPE can be used

Table 2.12. Film combinations possible with the blown film coextrusion system.

In contrast to cast film extrusion, where the individual layers are usually combined in a multilayer adaptor and distributed across the width of a cast film die, blown film extrusion operates with separate melt channels (Fig.2.13., 2.14.)

The advantage of the separate melt channels lies in the fact that raw materials of different viscosities are easier to combine, with the tolerances of the individual layers being mostly determinded by the design of the melt channels. The layer thickness ratios are easily adjustable by way of the extruder speeds, without parts of the blown film die having to be exchanged. The individual layers are then joined in the outlet area. The main melt streams are guided separately until they leave the die, and a common die gap can be created by fixing additional die lips. The common die gap protects the individual gaps against damage and oxidation.

The dimensions of the individual gaps for the main layers are, in the case of universal blown film dies, the same for all gaps. The gap widths range from 0.7 to 1mm, and the common die gap from 1.2 to 1.5mm. This die design permits layer thickness ratios from 1:2 to 1:3 when the same or similar materials are used. If greater thickness differences are required, materials with lower viscosity must be used for the thinner layers. If that is not possible, the die gap geometry must be adapted to the layer-thickness relationship. In the case of coextrusion dies, which can also extrude thin adhesive layers, this measure is already accounted for by reduced gap widths. The great market significance of blown film extrusion is due both to the continuously improved technology and to the development of new raw materials. Furthermore, there are the following process-related advantages which are a feature of the blown film process:

- The blown film process is well known to film producers, handling is simple and conversions can be carried out quickly.
- It is possible to produce very thin layers within a range from 2 to 5 μm.
- The lines are very flexible, and different film widths are obtained by selecting higher or lower blow-up ratios for the film tube. The film thickness is controlled by way of the take-off speed or the extruder output.
- By rotating the die and cooling ring, the nip roll station or the winding station, it is possible to produce cylindrical packages waste-free.
- The film can be wound as tube, laterally gusseted- or flat film.
- By varying blow-up ratios it is possible to improve the strength in the transverse direction, and the shrinkage properties.
- By slitting the tube it is also possible to operate waste-free when winding it as flat film. This is of particular advantage in the case of multicomponent films, as recycling treatment and possible applications of reground material are limited.

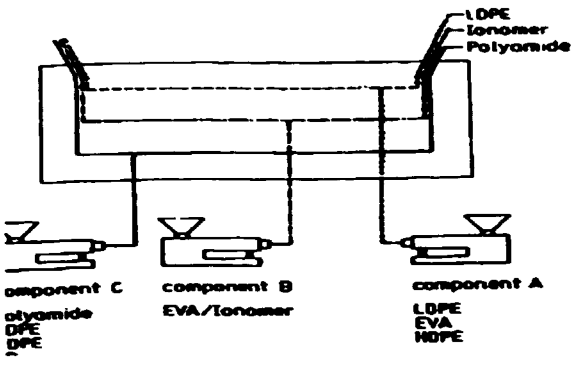


Figure 2.13. Diagram of three-layer coextrusion

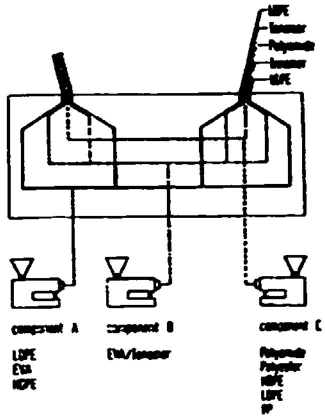


Figure 2.14. Diagram of five-layer coextrusion

2.5.2.Polymer Combinations and Properties

Raw materials are classified as support(Tab.2.15) , adhesion (Table 2.16.), or barrier materials (Tab.2.17), depending on their function.

Polymers	Properties	Special aspects of coextrusion
Support materials general	reasonably priced, good processability, very good availability and variety of types, good weldability, good printability	moisture barrier, increased strength, good transparency, good colorability, improved converting properties
LDPE	good processability, good transparency, good weldability, large variety of types, good availability, good water resistance, rel. low price	application in the MFI range from 0.3 to 2 g/10 min higher density = rigidity
EVA	with low VA content, same as LDPE improved weldability improved puncture resistance with VA contents above 8 to 10%: very good puncture resistance, good adhesion to PP (VA content > 18%), tendency to film blocking	like LDPE, preferably used on layers to be welded temperature-sensitive, must be purged with LDPE before extruder is shut down. As outer layer it can only be collapsed without creases with a roller collapsing frame
MDPE	higher rigidity than LDPE, higher strength, higher melting point, transparent, with narrow molecular-weight distribution more difficult to process	preferably as outer layer in order to prevent it from sticking to the welding beam; better converting properties
HDPE	high rigidity, good strength, low transparency	high strength is achieved in combination with LDPE when operating with a long neck
LLDPE	good transparency, good strength, relatively cheap, good weldability	no special blown-film head design necessary; can also be processed blended with LDPE
Ionomers	very good weldability, adhesion to PA, good puncture resistance, special types with increased shrinkage	because of aggressiveness special steels are required for melt channels; preferably as inner layer; ionomers must be purged out of the extruder before it is shut down
PC	very good transparency, good temperature resistance, high surface gloss, good strength	high processing temperature necessary; application limited to special cases

Table 2.15. Support materials, properties and special aspects of coextrusion.

Polymers	Properties	Special aspects of coextrusion
In general	good availability for all standard types, large MFI range	normal thicknesses: 3 to 5 µm; must be purged out before stopping the plant
Ionomers	good adhesion to LDPE and PA, EVA and LLDPE	larger primer layers improve mechanical properties of the film
Modified EVA	large number of types adapted for composite structures with LDPE, LLDPE, EVA, PA, EVOH, PC, PET	good processing: depending on composite, the adhesion can change up to two weeks after extrusion

Table 2.16. Bonding agents, properties and special aspects of coextrusion.

Polymers	Properties	Special aspects of coextrusion
Barrier material general	polymer with good gas-barrier properties, with foodstuffs: also aroma protection	required O_2-permeability approx. $1 \frac{cm^3}{m^2 \cdot 24\,h \cdot bar}$ for very sensitive foodstuffs such as wine, fruit juices; for meat, sausage, etc. from 20 to 80 $\frac{cm^3}{m^2 \cdot 24\,h \cdot bar}$
Copolyamides	specially for co-extrusion good transparency, good strength, trouble-free extrusion, good gas barrier, good availability	processing at 220 to 250 °C; application preferably with three-layer films, prevention of curling tendency by water-bath treatment; collapser with rollers necessary
Polyamide 6	better gas barrier than copolyamides, good transparency with special types, lower price than copolyamide, good availability	because of strong curling tendency with three-layer films it should preferably be used with five-layer films; processing temperature 240 to 260 °C; limited blow-up ratio
Polyester	good transparency, good gas barrier, as copolyester processable at low temperatures	processing temperature from 260 to 280 °C; small importance in blown film coextrusion
EVOH	very good gas-barrier (30 to 50 times better than PA), good transparency, high rigidity, increased brittleness, hygroscopic	temperature-sensitive, crease-break danger with thicknesses above 15 µm, preferably used with five-layer films

Table 2.17. Barrier materials, properties and special aspects of coextrusion.

2.5.3. Applications

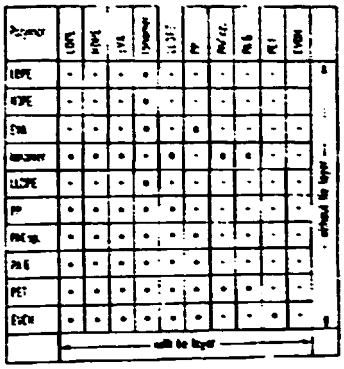
Coextrusion is employed for three reasons:

- improvement of conversion behavior,
- cost reduction,
- quality improvement.

Depending on the application, these criteria can be achieved individually or in combination.

There is no one thermoplastic which processes all the desired properties. The decision on which materials to use to form multilayer films will therefore depend largely on the properties required, but also on the price achievable.

For an optimum combination of polymers one must also take into consideration whether the chosen materials will adhere to each other or if bonding agents must be used. Table 2.18. shows the interrelationship for the polymers commonly used in the blown film process.



- • good adhesion without tie layer
- \- no adhesion
- ● adhesion dependent on type of polymer
- • good adhesion with tie layer, suitable bonding agents available

Table 2.18 Mutual bonding of various polymers

Within the limits that coextrusion offers one can develop a film structure on the basis of adhesion- and properties tables. Whet her such a combination will meet expectations can only be decided by tests or field experience. In practice, optimum multilayer films have been found for many fields of application by selection within the various polymer groups (Tab.2.19.)

Material combinations	Special properties	Most important fields of application
Double-layer film		
1. LDPE/LDPE	pinhole-free (multicolored)	milk film, carrier bags, general packaging
2. LDPE/EVA	good weldability, sterilizable	heavy-duty bags, stretch packaging, medical articles
3. HDPE/EVA	sterilizable	blood plasma, bakery goods, foodstuffs
4. HDPE/LDPE	good strength	bakery goods, foodstuffs, tomato concentrate
5. LDPE/ionomer	good weldability, puncture-resistant	dairy products, foodstuffs, medical instruments, general packaging
6. LLDPE/LDPE LLDPE/EVA	high elasticity good surface adhesion	stretch film
7. Ionomers/EVA	grease-proof	coconut, biscuits
8. Ionomers/PA	gas- and aroma-tight	meat, sausage, ham, fish, foodstuffs, cheese
Three-layer film, symmetrical		
9. LDPE/HDPE/LDPE	weldable on both sides, reduced curling tendency	like 4, pet food, cornflakes
10. EVA/PP/EVA	like 9	like 9
11. EVA/HDPE/EVA	like 3	like 9, cornflakes
Two-layer film with tie-layer (TL)		
12. LDPE/TL/PA	gas-, water- and aroma-tight	foamed PS granulate, meat, sausage, cheese, ham, fish, ready-made meals, bags
13. EVA/TL/PA	like 12 in hot-air channel good hot tack properties	like 12
14. Mod. EVA/TL/PA		like 12, vacuum packing for ham (shrinkable)
Three-layer film		
15. LDPE/HDPE/EVA	good weldability, good rigidity	bakery goods, foodstuffs
16. LDPE/EVA/PP	like 15	like 15
Five-layer film		
17. LDPE/TL/PA/TL/LDPE or LLDPE/TL/PA/TL/LLDPE	no curling tendency, improved barrier properties, as PA protected against moisture absorption, improved layer adhesion, weldable on both sides	like 12
18. EVA/TL/PA/TL/EVA	like 17	like 17
19. LDPE/TL/EVAL/TL/LDPE	like 17	like 17, fish meal, wine packaging, milk powder (casein)
20. EVA/TL/EVAL/TL/EVA	like 19	like 19

Note: LDPE can also be replaced by LLDPE (linear low density PE)

Table 2.19. Material combinations, special properties and import ant applications of coextruded blown films

3.Blow Moulding

3.1.Operation

The blow molding industry continues to be one of the fastest growing industries.Demand for industrial and technical molding containers, irregular hollow shaped industrial parts, and bottles is predicted to grow significantly. Products range from small to large containers used in packaging, transportation, toys, house wares, etc.

Blow molded components are eroding the market for traditional materials, particularly in liquid packaging applications. Bottle and liquid container applications dominate the market. Since the area of the introduction of polyethylene (PE) squeeze bottles for washing-up liquid, polyvinyl chloride (PVC) or cooking oils and fruit sqash bottles, polyethylene terephthalate (PET) for carbonated beverage bottles, and others, there has been, in the last decade, rapid advances, not only in the process machinery, but aslo in the characteristics and range of materials available.

The basic consumer polymers, the polyolefines (PE, PP), PVC and today, PET, are increasingly being combined with special barrier layer materials. Oxygen and water vapor resistant coatings are successfully preserving flavor and extending product shelf life. New process technology brings wide scale introduction of multilayer containers to our supermarket shelves much closer and companiers are capitalizing on the progress achieved to date.

Understanding how to obtain the maximum performance of each individual operation in the complete Blow Molding Operation and properly integration each step to meet product performance at the lowest cost is important to all people in the plant as well as management. A block diagram on the complete Blow Molding Operation that meets the Fallo approach (Follow All Oportunities) is in Fig.3.1. Targeting for low cost is summarized in Fig.3.2.

Basically, the Fallo approach is to: (1) design a part to meet performance and manufacturing requirements at the lowest cost, (2) specify the proper plastic molding material that provides part performance after processing, (3) specify equipment requirements and (4) purchasing and warehousing materials.

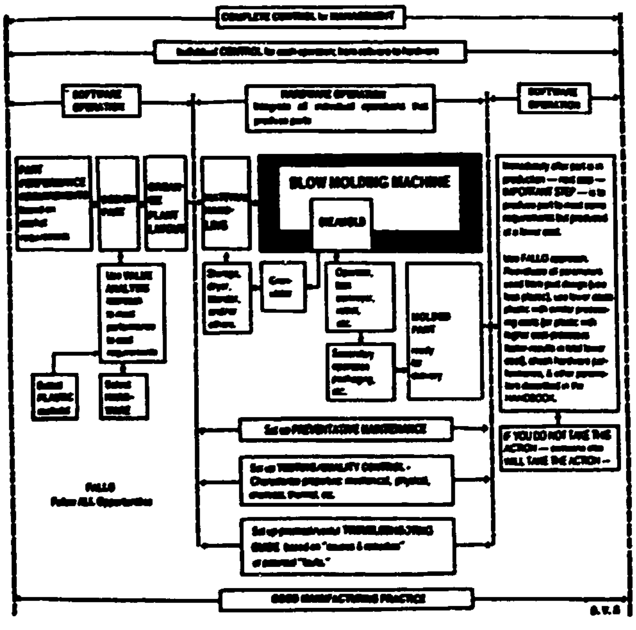


Fig.3.1. Complete blow molding operation - the FALLO aproach is to Follow All Opportunities. This block diagram basically summarizes what should be considered to ensure a good return on investment to produce all types and shapes of plastic blow molded products, including those that will open new markets where practically any shape can be produced. The block diagram meets the objective of this one-source book in bringing you up to date on today's technology as well as what is ahead. To blow mold, many important steps are involved - steps that must come together properly to produce parts consistently meeting performance requirements at the lowest cost. This diagram provides only a summery and introduction to all the important steps reviewed in this chapter. Basically the approach is to design parts to meet specific requirements, specific plastic based on the process to be used and specify equipment requirements by (a) designing mold "around" the part, (b) put the proper performing equipment around the die or mold, (c) setup auxiliary equipment to "match" and properly "interrelate", (d) setup complete controls such as quality control, troubleshooting guides, preventative maintenance, etc. Result is to meet "zero" defects, meet performance (customer) requirements and produce targeted profit.

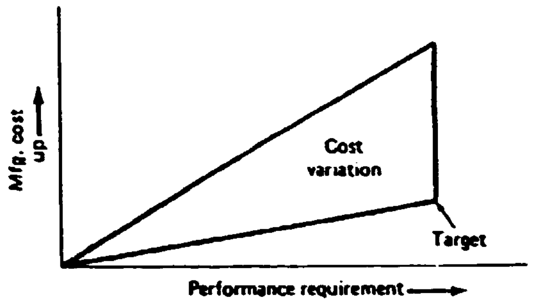


Fig.3.2. Costing is an indispensible economic aid for management and requires understanding and controlling all aspects of operations such as those summarized in Fig.3.1. It includes effective plant management and financial control. As shown by this diagram, target is to blow mold products that meet performance require ments at the lowest cost.

Different types of plastics are used to produce various blow molded parts. Typical blow molding processes are summarized in Table 3.3. The major process used which consumes almost 75% of all blow molded plastic materials is extrusion blow molding (continuous, wheel clamp, intermittent, accumulator and stretch). The other process that consumes almost 25% is injection blow molding (stretched and unstretched).

Basic process	Materials	Average production rate, parts per hour	Average container size	Approximate market penetration, percent
Continuous extrusion shuttle clamp	Polyethylene (PE), polypropylene (PP), polycarbonate (PC), polyvinyl chloride (PVC), polyethylene terephthalate glycol modified (PETG)	500 to 3,600	4 ounces to 7-1/2 gallons	50
Wheel clamp (6 to 24 clamps)	Polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP), coextrusions	2,000 to 5,000	32 to 300 ounces	10
Intermittent extrusion reciprocating screw	Polyethylene (PE) and polycarbonate (PC)	500 to 2,500	8 to 128 ounces	10
Accumulator head	Polyethylene (PE) and engineering plastics	50 to 500	5 to 2,000 gallons	5
Stretch blow molding	Polyvinyl chloride (PVC), polyethylene terephthalate (PET), polypropylene (PP), polyacrylonitrile (PAN)	1,200 to 4,000	16 to 48 ounces	20 (including reheat)
Injection blow molding	Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polycarbonate (PC), polyacrylonitrile (PAN), polystyrene (PS)	500 to 3,000	1 to 16 ounces	5 (including dip molding)
Dip blow molding	Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyacrylonitrile (PAN), polystyrene (PS)	500 to 1,500	1 to 24 ounces	(see injection blow molding)
Reheat blow molding	Polyethylene terephthalate (PET)	240 to 15,000 1,200 to 4,000 1,200 to 4,000	16 ounces to 22 liters 16 to 48 ounces 8 to 48 ounces	(see stretch blow molding)

Table 3.3. General types of blow molding processes

3.2.Extrusion Blow Molding

In extrusion blow molding (Fig.3.4.-3.9.), a parison is formed by an extruder. Basically the plastic is melted by heat which is transferred through the barrel by the shearing action of the extruder screw as it passes through the extruder. The helical flights of the screw change configuration along its length from input to output ends to assure a uniformly homogeneous melt.

Turning continuously, the screw feeds the melt through the die -head as an endless parison or into an accumulator. Size of the part and the amount of material necessary to produce the part (shot size) dictate whether or not an accumulator is required. The nonaccumulator machine offers an uninterrupted flow of plastic melt.

With the accumulator, flow of parison through the die is cyclic. The connecting channels between the extruder and the accumulator and within the accumulator itself, are designed rheologically to prevent restrictions which might impede the flow or cause the melt to hang up. Flow paths should have low resistance to melt flow to avoid placing unnecessary load on the extruder.

When the parison or tube exits the die and develops a preset length, a split cavity mold closes around the parison and pinches one end. Compressed air inflates the parison against the hollow blow mold surfaces which cool the inflated parison to the blow mold configuration. Upon contact with the cool mold wall, the plastic cools and sets the part shape. The mold opens, ejects the blown part, and closes around the parison to repeat the cycle.

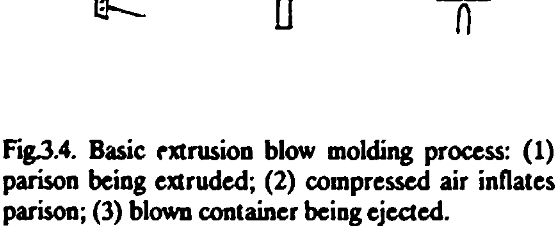


Fig.3.4. Basic extrusion blow molding process: (1) parison being extruded; (2) compressed air inflates parison; (3) blown container being ejected.

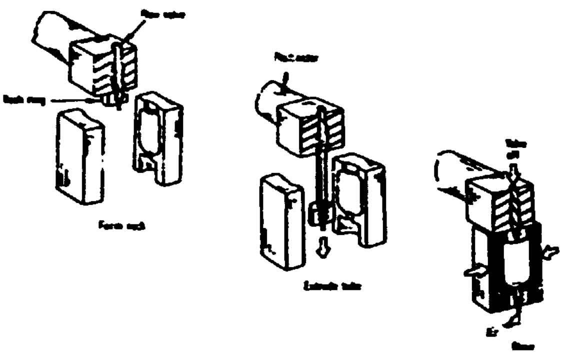


Fig.3.5. Neck ring process (Monsanto Co.).

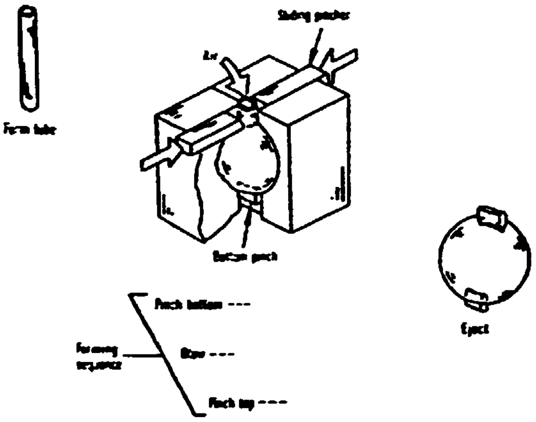


Fig.3.6. Trapped air process.

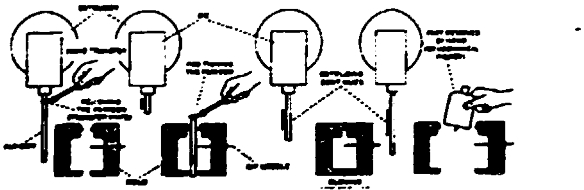


Fig.3.7. Parison transfer. One system of continuous extrusion blow molding uses transfer arms to remove the parison from the die and transfer it to the molds. This system may use several heads, and transfer several parisons. In most machines of this type, the parison is placed over blow pins and the bottles are blown in an inverted position. This system can be used to produce bottles with finished necks that do not require post-finishing operations other than detabbing. Schematic shows hand transfer. However, production machines use electromechanical transfer systems.

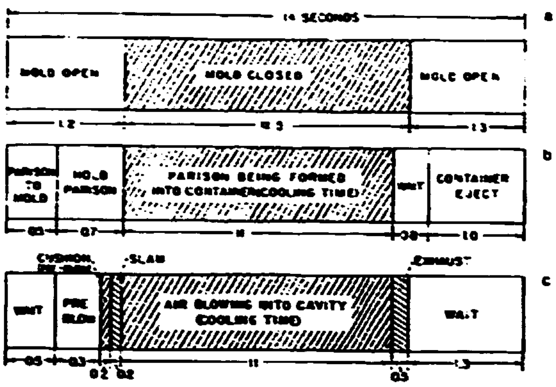


Fig.3.8. Extrusion blow molding cycle. A complete cycle graph showing a typical blow molding cycle for 5 liter containers. Phases a, b, and c illustrate the breakdown of blow molding cycles.

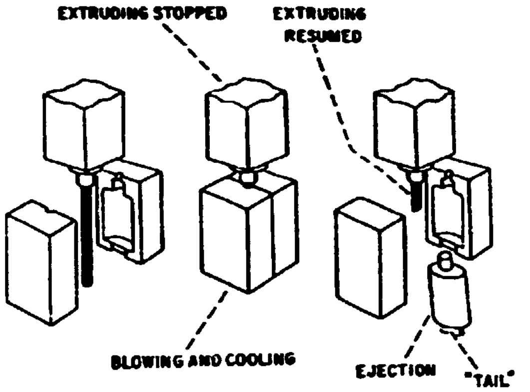


Fig.3.9. Schematic of intermittent parison extrusion into a stationary mold. Extruder operation is interrupted after the parison has reached the desired length and before the mold halves have closed around it (left). Operation is resumed at the end of the ejection step (right). (U.S.I. Chemicals)

3.3.Injection Blow Molding

Injection blow molding has basically three stages (see Fig.3.10.-3.13.). In the first stage, plastic melted in a reciprocating screw extruder is injected into a split steel mold cavity to produce a preform parison, which in turn, is temperature conditioned for later blow molding. The preform is shaped much like a test tube with screw finish at the top. This finish, of course, is the final finish of the bottle and is molded to close tolerances.

The preform is transferred on a core rod to the second and blow molding stage. Here air is blown through the core rod to expand the conditioned preform against a cold, usually aluminium, blow mold cavity. The container has now been produced.

In the third stage, the container is transferred again on the core rod. The finished container is transferred to the third stage where it is ejected from the machine.

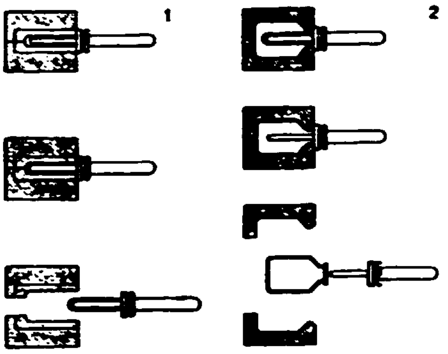


Fig.3.10. Basic injection blow molding process: (1) injection preform; (2) blow molding and ejection.

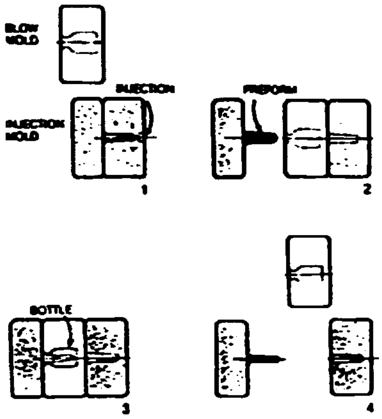


Fig.3.11. Basic shuttle-type injection blow molding process (using conventional injection molding machine; Husky Machine Co.). (1) Preform injection molded; (2) blow mold moves into position; (3) blow cycle; (4) blow mold raised with finished parts.

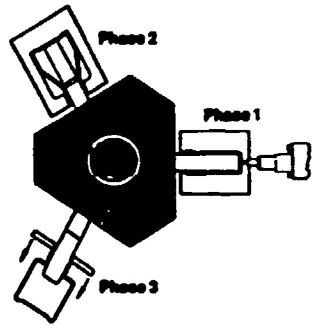


Fig.3.12. Schematic of injection molding process: phase 1 - Preform molding via injection molding machine; phase 2 - blow molding; phase 3 - ejection.

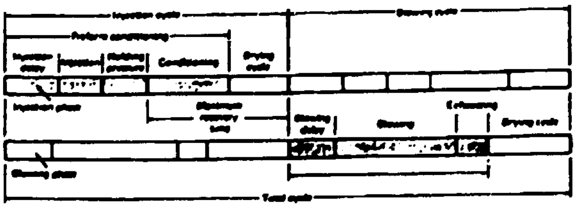


Fig.3.13. Injection blow molding cycle.

3.4.Stretch Blow Molding

Since the late 1970s stretch blow molding (Fig.3.14.-3.20.) has become an important high speed, high production technique, largely due to the 2-liter carbonated beveragy bottle that uses PET resin. A variety of other bottling applications exist such as foods, cosmetics, etc. Stretched polypropylene (extrusion) blow molded bottles have been used since the early 1970s principally for packaging detergents.

The importance of molecular orientation is widely recognised. By biaxially stretching the extrudate before it is chilled in the mold, real improvements to the finished bottles can be obtained. This technique allows the use of lower material grades or thinner wall thickness; both approaches reduce material costs.

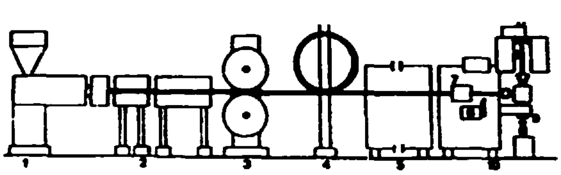


Fig.3.14. Extrusion stretch blow mold. Diagrammatic representation of the Hercules/Bekum OPP bottle line: (1) Extruder; (2) Sizing baths; (3) Haul-off; (4) Loop stand; (5) Reheat oven; (6) Cutter, (7) Puller, (8) Mold closing unit neck calibration; (9) Clamping system; (10) Stretch blow molding machine.

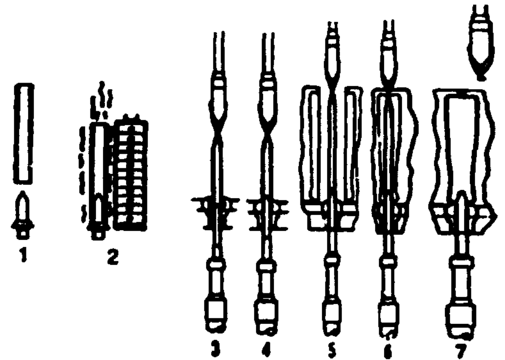


Fig.3.15. The Orbet Process (of Phillips 66 Co.) is a two-step process designed to again the advantages of material orientation in the blown ware. Continuous extrusion of tubing for the parison is extruded and cut to length separately. These cold parison tubes are loaded on spindles that travel through a carefully heat controlled oven. After passing through a programmed heating procedure, the hot plastic tube-parisons are picked up by a clamp which transports them to the blow spindle where the end is clam ped in the neck ring. At this point, the picker rises to stretch the parison; following the stretch which provides axial orientation, the mold halves clamp together and the "blow" expands the form into the finished product with orientation perpendicular to the axis. This process is particularly suitable for polypropylene and the bottle thus produced has particularly desirable proper ties. Molds are similar to other blow molds.

Producing a biaxially oriented bottle: (1) parison is positioned on the rotor pin; (2) programmed radiant heating is applied to parison wall; (3) picker places the heated parison on the blowing/swage; (4) threaded dies close on the parison and swage up to compression mold the bottle neck; (5) picker ascends, vertically orienting the parison; (6) mold closes and bottom pinchoff is served by tapered steel sutters in the mold; (7) bottle is blown (upside down) as picker removes the tail pinchoff.

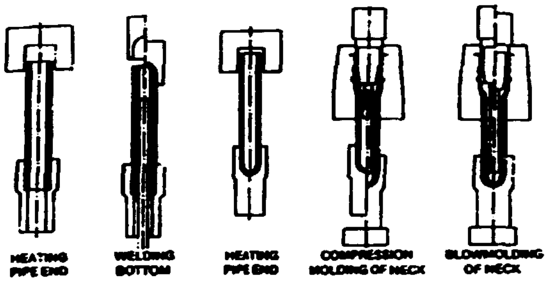


Fig.3.16. The central idea of the Corpoplast process is the production of bottles in two stages, beginning with a cold inter mediary stage - the preform. The preform is already a container closed on one end, although its diameter is considerably smaller than that of the bottles formes from it. This preform is rapidely and precisely warmed in the machine according to set values within the thermoelastic deformation range of the material, and then expanded by blowing to the predeterminded bottle shape.

The geometrical shape of the preform is designed to result in the container shape to be obtained by blowmolding. The heating process is differentiated in such a way that the degree of stretching, in association with the specific properties of the material, will produce optimal biaxial orientation over the entire surface area. In the thermoelastic forming range, much below the melting temperature, material molecules can be oriented by mechanical stretching. This orientation, in a preferential direction, creates substantial improvement of physiacal properties such as strength, modules of elasticity and permeability. The container grows during blowing both in diameter as well as in length. In this way it acquires a biaxial orientation, i.e. running in two directions parallel to the surface.

The sequence of operations illustrated here converts an extruded tube into a necked parison. (Krupp Corpoplast)

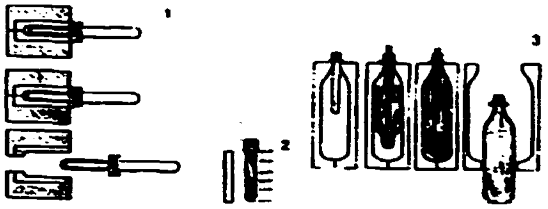


Fig.3.17. Basic stretch injection blow molding process (two-step). (1) Injection preform; (2) reheat preform; (3) stretch blow molding and ejection.

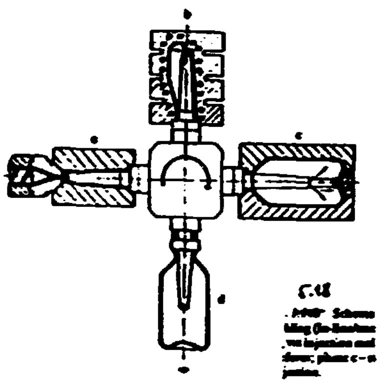


Fig.3.18. Schematic of stretch injection blow molding (in- line/one-step): phase a - preform molding via injection molding machine; phase b - reheat preform; phase c - stretching and blowing, phase d - ejection.

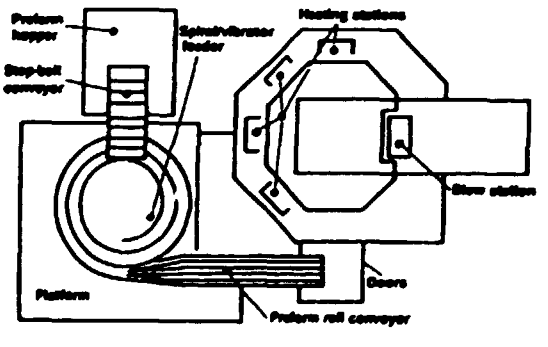


Fig.3.19 Reheat stretch-blow molding machine that can make up to 2,000 bottles/hr from injection molded preforms of PET, PVC, PAN, and other thermoplastic materials has been introduced by Batten feld Fischer.

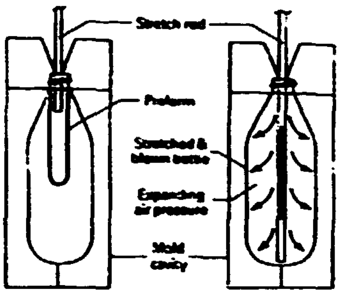


Fig.3.20. A temperature conditioned injection preform is inserted into the blow mold cavity, then is rapidly stretched. Often a road is used to stretch the preform in the axial direction with air pressure to stretch the preform in the radial direction.

The stretch-blow process can give many resins improved physical and barrier properties. In biaxial orientation, bottles stretched lengthwise by an external gripper, or by an internal strech rod, and then stretched radially by blow air to form the finished container against the mold walls. This process alings the molecules along two planes providing additional strength, and even more important, better barrier properties than is possible without biaxial orientation. Other advantages include better clarity, increased impact strength, or toughness, and reduced creep. The actual increase is dependent on the ratio of blow up in each direction.

The process allows wall thickness to be accurately controlled and also allows weights to be reduced, so lowering material costs. Further the cost of reheating the material is offset by the elimination of scrap produced at the neck and base by the other production system.

3.5.Multi-Layer Containers

The barrier requirements to meet package needs vary depending on the product being packed. Properties that may need to be retained can include gases, water vapor, aroma, taste, solvents, etc. In addition, every barrier package must respond to the specific customers's processing techniques and distribution system. The result has been the development of a wide diversity of barrier container technologies and processes.

There are three basic ways in which to increase the barrier properties of a rigid plastic container. The first is to improve the barrier properties of the single polymer or copolymer being used in a mono-layer container. The second is to place a barrier coating on either the inside or the outside of the mono-polymer layer. The third is to employ several distinct polymers in a multi-layer structure with each providing a different specific barrier or performance quality.

The following processing technologies are suitable:

- coextrusion,
- coextrusion blow molding
- coinjection blow molding
- coinjection stretch blow molding.

4.Extrusion Recycling of Plastics Waste

4.1.Operations

In the fifties the first attempts were made to reclaim plastics waste and to make it useful for processing. For the most part primitive reclaim techniques were used, and unsatisfactory results obtained.

Since then plastics recycling has developed into a high-level technology comparable with other outstanding technologies in plastics processing.

Many circumstances contribute to the problematic aspects of recycling. Among these is the fact that when primary products are manufactured, thought is seldom given to scrap recovery methods.

Problems in the re-use arise with colored scrap, coatings on metal, textiles or paper, and with coextrusions.

Additional influences include UV- and thermo-oxidative ones, dirt, foreign bodies and moisture.

The various technologies required for reclaiming are also determined by the form of the materials, such as fibres, films, pipes, profiles, and many others.

In practice today recovery methods are of three basic types:

Chemical processes	Mechanical processes	Thermal processes
- pyrolysis	- granulating	- extrusion
- hydrolysis	- densification	
	- agglomeration	

A deeper study of the different recycling processes shows the following:

- pyroloysis requires great technological effort and big investment. Thus, the economics of this approach remain in doubt, at the time being.
- hydrolysis is only useful for particular kinds of plastics; end products are monomers, the basic components of the plastic.
- granulating, densification, and agglomeration are reclaiming processes which do not affect quality, since they are merely physical processing steps. They can be used indepenently, but are usually part of complete extrusion systems.

Extrusion of waste materials reveals a totally different situation:

- specific reclaim costs are low,
- investment costs are low; production capacities range from 50 kg/h to well above 1000 kg/h,
- high quality product is obtainable thanks to the well-defined and controllable nature of the process,
- the waste materials can be modified during the process,
- there is a wide variety of applications, and practically all thermoplastics can be processed,
- in special cases a final product is manufactured directly from the waste, without intermediate pelletizing.

4.2.Melt Recycling

With well-designed plants, the overall process should be carried out in precisely defined, individually controllable steps.

The complete plant is only as good as its individual components, which must be properly interfaced to create a smoothly operating processing unit.

Figure 4.1 shows the typical flow sheet and a schematic layout of a recycling plant for film and fiber waste. Incoming material is fed (a) past a metal detector (b), to a granulator (c); pneumatic conveyor (d) then moves the chopped material to a stock silo (e). Conveying air is released through a cyclone or exhaust filter (f). The crammer feeder (k) receives clean material direct from the stock silo, or contaminated material via a washing plant (g). A metal separator (i) is placed between crammer feeder and stock silo. The fliffy cut-film scrap is densified and force-fed to the extruder (l) by the crammer feeder. The extruder plastifies, homogenizes, degasses (if required), and conveyes the melt into the screen changer (o) which filters contaminating materials from the melt. The melt-pressure measuring unit (n) indicates when internal screen changing occurs. The melt-temperature measuring unit (m) measures the melt tmperature. Upon passing the screen changer the melt streams through the die head (p) and through lace dies with linear or circular hole patterns, to be cut by the die face pelletizer (q).

The lens-shaped pellets are cooled by water for an appropriate distance and then move to the pellet dryer (s). The dryer removes surface water from the pellets, but leaves some residual moisture, which is necessary for further processing.

The cooled pellets are then run over a classifying screen (t) to seperate over- and undersized particles. Depending on the conveying distance involved, either a blower (u), or a vacuum system with a star valve is used to convey into the storage silo (v). A station for weighing and filling bags (w) or other containers can also be provided.

The individual processing steps are:

– granulation	metal separation*
– conveying	plastication and homogenizing*
– storage	degassing*
– densification	melt filtration*
– washing	pelletizing*

The starred * steps are quality-defining and quality-influencing factors - the others are regarded more or less to be quantity- or efficiency-influencing elements.

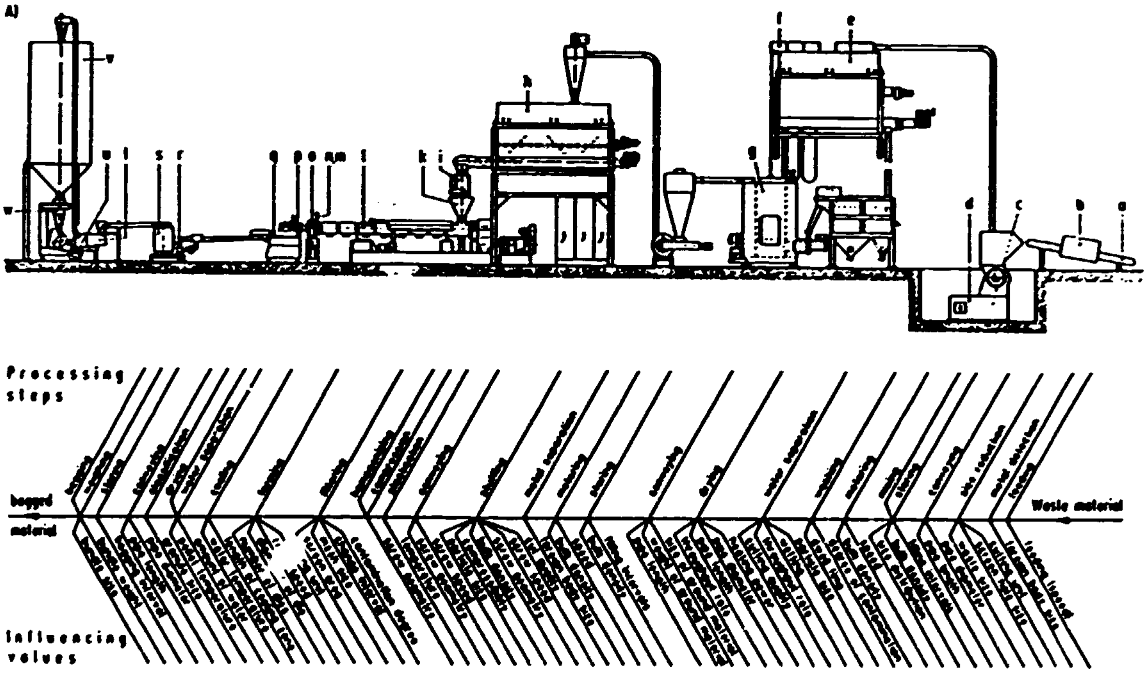


Figure 4.1. Principle of reclaiming waste plastic (film, fibres, etc.) by extrusion (a) conveyer belt, (b) metal detector, (c) granulator, (d) conveyor blower, (e) stock silo, (f) exhaust filter, (g) washing plant, (h) stock silo, (i) metal separator, (k) crammer feeder, (l) extruder, (m) melt-temperature sensor, (n) melt-pressure sensor, (o) screen changer, (p) pelletizing die head, (q) water-cooled die-face pelletizer, (r) water container with circulating pump, (s) spin- dryer, (t) classifying screen, (u) pellet-conveyor, (v) pellet silo, (w) bagging scale

4.3.Applications

Thermoplastic waste is devided into the following categories for practical purposes:

- bulk plastics: LDPE, HDPE, PS, PP, ABS, SAN, PVC,
- engineering plastics: PA, PETP, PC, and similar resins,

and into the following types:

- in-line factory waste (unused),
- used waste.

Unfortunately the waste is not often available in a segregated condition, and mixtures of widely differing materials cause great problems in reclaiming and subsequent processing.

Table 4.2. shows the compatibility of different thermoplastics. The reclaiming processes differ according to the quality and type of the thermoplastic waste material; these may be classified as follows:

- standard process for in-line waste,
- washing and reclaiming process for contaminated waste,
- reclaiming plus compounding in a single process for filling and alloying at the same time,
- special process for engineering plastics,
- direct reclaiming from waste to the final product, with filling if necessary.

	Standard PS	HIPS	SAN copolymer	ABS	PA	PC	PMMA	POM	PVC	PP	LDPE	HDPE	PBT
Standard PS													
HIPS	1												
SAN-copolymer	6	6											
ABS	6	6	1										
PA	5	4	6	6									
PC	6	5	2	2	6								
PMMA	4	4	1	1	6	1							
POM	6	6	6	5	6	6	5						
PVC	6	6	2	3	6	5	1	6					
PP	6	6	6	6	6	6	6	6	6				
LDPE	6	6	6	6	6	6	6	6	6	6			
HDPE	6	6	6	6	6	6	6	6	6	6	1		
PBT	6	6	6	5	5	1	6	6	6	6	6	6	
PET	5	5	6	3	3	1	6	6	6	6	6	6	6

Table 4.2. Miscibility of different thermoplastics. The miscibi lity decreases from 1 to 6, i.e. 1 means very good miscibility, 6 incompatibility.

5.Annex A: Literature

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6.Annex B: Selected Suppliers

(Extract of Catalogue of the Plastic Exhibition K89, 2-8 November 1989, Düsseldorf, FRG)

Extruder
Extruders
Machines d'extrusion
Estrusori
Máquinas de extrusión

Einschneckenextruder
Single-screw extruders
Extrudeuses monovis
Estrusori monovite
Extrusionadoras de un husillo

Achenbach Plastic-Maschinen
A.D.S. S.A.
Afex Maschinenbau
Alpine Aktiengesellschaft, Kunststoffverarbeitungsmaschinen
Amut S.p.A.
APV Chemical Machinery Limited
Arenz GmbH
Arvor GmbH
Automatik Apparate-Maschinenbau
Axon AB Kunststoffmaschinen
Bandera Luigi S.p.A.
Barmag AG
Barwell International Ltd.
Bassani Mascheroni & C Srl
Battenfeld Extrusionstechnik
Bekum Maschinenfabriken GmbH
Beringer USA/Swisscab
Berstorff Maschinenbau GmbH
Betol Machinery Ltd.
B.G. Plast Srl
Boston Matthews Machinery
Brampton Engineering Inc.
Breyer GmbH, Maschinenfabrik
Cellier S A.
Cincinnati Milacron
Colines PP&P S.r.l.
Colines s.r l., Gruppo
Dr. Collin GmbH
Colmec S.p.A.
Comago s.r.l.
Covema s.p.a., Nuova
Dalaker Kunststoffmaschinen
Davis-Standard
Davis-Standard
Dipiemme Dies
Dolci S.p.A., Ing. L.
Egan Machinery Division
Erema GmbH
ER-WE-PA Maschinenfabrik
Extrudaids Limited
Extrudex Kunststoffmaschinen
Fairex
Falcon
Farè S p A.
Farrel Corporation
Farrel Ltd.
F.B.M. s.r.l. Falzoni
Ferrostaal AG
Fong Kee Iron Works Co.
Formac s.r.l.
Friul Filiere s.r.l.
Future Design Inc.
Garant Maschinenhandel
Gillard & Co. Ltd.
Gimac di Maccagnan
Gmehling -maGme-
Gumix, S.A.
Gebrüder Haake
Ide, Bernhard
Imexo-Fornoff
Indemo S.A.
Industrie Generali Group
Italwork s.a.s.
Jofra Maschinen
Killion Extruders
Krauss-Maffei
Krupp Bellaplast
Krupp Maschinentechnik
Kuhne GmbH
Leistritz
Lenzing AG
Leonard di Ugo Castelnovo
Lung Meng
Macchi S.R.L.
Machinery Bellora
Macro Engineering
Mai Virginio s.r.l.
M.A.M. - Meccanica
Mat Plast Sarl
McNeil Akron Repiquet
Müller + Sohn AG, Paul
Nokia - Maillefer
Olmas S.R.L.
Omam S.P.A.
O.M.C. S.r.l.
Omicron Plann s.r.l.
Omipa S.p.A.
O.M.V. - Officine
Plastbau Spinntechnik
Plastik-Maschinenbau GmbH
Plastmachines Gelderland
Pomini Farrel SpA
Prandi G. & C. S.p.A.
Prealpina S.r.l.
Previero N. S.r.l.
Promatech s.r.l.
R C M AG, Rubber Consulting + Machinery
Reifenhäuser GmbH & Co.
Scamia
Schlicht, Rolf
Schwabenthan Maschinenfabrik
Sentinel Machinery
Shaw & Co.
Somaplast snc
Sorema s.r.l.
Steelastic
Technoplast Kunststofftechnik
Tecma Italia S.r.l.
Tecom S.r.l.
Theysohn-Extrusionstechnik
Thyssen Edelstahlwerke
Toshiba Machine (Europe)
Trimec SAS
Troester Maschinenfabrik
Union off. mecc. s.p.a
Weber Maschinenfabrik
Welding Engineers
Welex Inc.
Werner & Pfleiderer
Western Polymer Division
Wilmington Machinery
Windmöller & Hölscher
Woywod Kunststoffmaschinen
Yvroud S.A.
Zeta Plastic Sales

Doppelschneckenextruder
Twin-screw extruders
Extrudeuses bivis
Estrusori bivite
Extrusionadoras de dos husillos

actual Anlagen-, Maschinen- und Werkzeugbau
Amut S.p.A.
APV Chemical Machinery Limited
Bandera Luigi S.p.A.
Bassani Mascheroni & C Srl
Battenfeld Extrusionstechnik
Bausano Group SpA
Berstorff Maschinenbau GmbH
Betol Machinery Ltd.
Cincinnati Milacron
Clextral
Dr. Collin GmbH
Comacplast s.n.c.
Covema s.p.a., Nuova
Davis-Standard
Dipiemme Dies
Egan Machinery Division
esde Maschinentechnik
Extrudaids Limited
Feddersen & Co.
Fong Kee Iron Works Co.
Friul Filiere s.r.l.
Gebrüder Haake
Ide, Bernhard
Imexo-Fornoff
Industrie Generali Group
Jofra Maschinen
Kraftanlagen Aktiengesellschaft
Krauss-Maffei
Leistritz
LMP Impianti
Lung Meng
Maplan International
Mapre S.A.
Maris S.p.A.
Mat Plast Sarl
McNeil Akron Repiquet
Omam S.P.A.
O.M.C. S.r.l.
Plastik-Maschinenbau GmbH
Plastiprogram s.r.l.
Reifenhäuser GmbH & Co.
Rockstedt oHG
De Rollepaal BV
Schwabenthan Maschinenfabrik
Sentinel Machinery
Speedex (Engineering)
Tecma Italia S.r.l.
Theysohn Maschinenbau
Theysohn-Extrusionstechnik
Thyssen Edelstahlwerke
Toshiba Machine (Europe)
Trimec SAS
U.S. Extrusion, Inc.
Weber Maschinenfabrik
Welding Engineers
Werner & Pfleiderer

Sonstige Extruder

Extruders for other design
Autres extrudeuses
Altri estrusori
Otras extrusionadoras

actual Anlagen-, Maschinen- und Werkzeugbau
A.D.S. S.A.
Anthony Crowe AG
Axon AB Kunststoffmaschinen
Bandera Luigi S.p.A.
Barmag AG
Barwell International Ltd.
Bassani Mascheroni & C Srl
Battenfeld Extrusionstechnik
Bekum Maschinenfabriken GmbH
Beringer USA/Swisscab
Berstorff Maschinenbau GmbH
Cellier S.A.
Colines PP&P S.r.l.
Colines s.r.l., Gruppo
Color Metal GmbH
Comacplast s.n.c.
Comago s.r.l.
Covema s.p.a., Nuova
Davis-Standard
Dipiemme Dies
Düspohl Vertriebs GmbH
Egan Machinery Division
Entex Rust & Mitschke
ER-WE-PA Maschinenfabrik
Extrudaids Limited
Extrudex Kunststoffmaschinen
Fairex
Farrel Corporation
Farrel Ltd.
Fong Kee Iron Works Co.
Frank OHG
Friul Filiere s.r.l.
Gelaplast
Gimac di Maccagnan
Gebrüder Haake
Ide, Bernhard
Industrie Generali Group
Killion Extruders
Krupp Maschinentechnik
Leonard di Ugo Castelnovo
Lung Meng
Macchi S.R.L.
Mai Virginio s.r.l.
McNeil Akron Repiquet
Müller + Sohn AG, Paul
Omam S.P.A.
O.M.C. S.r.l.
Plastik-Maschinenbau GmbH
Prandi G. & C. S.p.A.
Promatech s.r.l.
Pyles Division
R C M AG, Rubber Consulting + Machinery
Steelastic
Tecma Italia S.r.l.
Theysohn Maschinenbau
Thyssen Edelstahlwerke
Weber Maschinenfabrik
Werner & Pfleiderer
WK Worek

Extruderfolgemaschinen

Follow-on equipment for extruders
Matériel auxiliaire d'extrusion
Attrezzature ausiliarie per impianti di estrusione
Dispositivos auxiliares para la extrusión

Accrapak Systems Ltd. Strand Pelletisers, Sieves, Air Knives
Achenbach Plastic-Maschinen
actual Anlagen-, Maschinen- und Werkzeugbau
Afex Maschinenbau
Alpine Aktiengesellschaft, Kunststoffverarbeitungsmaschinen
Amut S.p.A.
Axon AB Kunststoffmaschinen
Bandera Luigi S.p.A.
Barmag AG
Bassani Mascheroni & C Srl
Bastian Wickeltechnik GmbH
Battenfeld Extrusionstechnik
Battenfeld Gloenco
Bausano Group SpA
Berstorff Maschinenbau GmbH
Betol Machinery Ltd.
Boston Matthews Machinery
Breyer GmbH, Maschinenfabrik
Brückner - Maschinenbau
Calini G. Fabbrica Macchine
Cellier S.A.
Cincinnati Milacron
The Cloeren Company
Dr. Collin GmbH
Colmec S.p.A.
Color Metal GmbH
Colsmann & Kirschner
Condux Maschinenbau
Covema s.p.a., Nuova
Davis-Standard
Dipiemme Dies
Dolci S.p.A., Ing. L.
Egan Machinery Division
Elmepla s.r.l.
Entex Rust & Mitschke
Erema GmbH
ER-WE-PA Maschinenfabrik
Euromac Costruzioni
Exact Attrezzature
Extrudaids Limited
Extrudex Kunststoffmaschinen
Fairex
Falcon
Farè S.p.A.
FAS Converting Machinery
Ferrostaal AG
Flynn Burner Corporation
Fong Kee Iron Works Co.
Formac s.r.l.
Fränkische Rohrwerke
Future Design Inc.
Gerlach GmbH
Gillard & Co. Ltd.
Gimac di Maccagnan
Gnata Filippo & C.
Graewe GmbH, Kurt
Gumix, S.A.
Gebrüder Haake
HACOBA-Textilmaschinen
vom Hagen + Funke
Hegler Plastik GmbH
von Hein GmbH
Heuser, Hans
Hofmann + Schwabe
Ide, Bernhard
Imexo-Fornoff
Industrie Generali Group
INOEX GmbH
In.Set. Industriale Settala
IPM S.n.c.
Italwork s.a.s.
ITIB S.p.A.
Kampf GmbH & Co.
Killion Extruders
Kraftanlagen Aktiengesellschaft
Krauss-Maffei
Krupp Bellaplast
KUAG - Kunststoffmaschinen
Lico S.p.A.
LMP Impianti
Maag Zahnräder AG
Macchi S.R.L.
Mai Virginio s.r.l.
Maier Heidenheim
M.A.M. - Meccanica
Maplan International
Maris S.p.A.
Mat Plast Sarl
Matthews-Niescher GmbH
Mazzoni s.r.l.
Mecanor AB, Oy
Gebrüder Menzel
Mouzon S.A., G.
Nokia - Maillefer
Norcoil Trading A.S.
Nuova Protex
Oleotti, Pio
Olmas S.R.L.
O.M.C. S.r.l.
Omicron Plann s.r.l.
Omipa S.p.A.
Plastik-Maschinenbau GmbH
Plastiprogram s.r.l.
Plastmachines Gelderland
Prealpina S.r.l.
Previero N. S.r.l.
Promatech s.r.l.
R C M AG, Rubber Consulting + Machinery
Reifenhäuser GmbH & Co.
Reinhold, Klaus
Rockstedt oHG
De Rollepaal BV
Scheer & Cie.
Schlicht, Rolf
Schwabenthan Maschinenfabrik
Senn AG, Georg
Sentinel Machinery
Shaw & Co.
Sherman Treaters Ltd.
S.I.C.A. S.p.A.
Softal electronic
Somaplast snc
Sorema s.r.l.
Southwest Screens and Filters
Speedex (Engineering)
Stahlkontor Maschinenbau
Sulzer, Gebrüder
Tecma Italia S.r.l.
Tecnova Snc
Tecom S.r.l.
Theysohn-Extrusionstechnik
Trendelkamp GmbH u. Co. KG
Trimec SAS
Troester Maschinenfabrik
Truplast Kunststofftechnik
Uni-Flo
Union off. mecc. s.p.a
Urban GmbH & Co.
VMI Epe Holland
Vobau, Artur Baston
Weber Maschinenfabrik
Welex Inc.

Extrusionsanlagen für Flachfolien

Extrusion plants for flat sheet
Installations d'extrusion de feuilles à filière plate
Linee di estrusione a testa piana per foglie
Instalaciones de extrusión para láminas planas

- Afex Maschinenbau
- Amut S.p.A.
- APV Chemical Machinery Limited
- Axon AB Kunststoffmaschinen
- Bandera Luigi S.p.A.
- Barmag AG
- Battenfeld Extrusionstechnik
- Battenfeld Gloenco
- Berstorff Maschinenbau GmbH
- Betol Machinery Ltd.
- B.G. Plast Srl
- Breyer GmbH, Maschinenfabrik
- Brückner - Maschinenbau
- Cellier S.A.
- Cincinnati Milacron
- The Cloeren Company
- Colines PP&P S.r.l.
- Colines s.r.l., Gruppo
- Dr. Collin GmbH
- Covema s.p.a., Nuova
- Davis-Standard
- Dipiemme Dies
- Dolci S.p.A., Ing. L.
- Egan Machinery Division
- ER-WE-PA Maschinenfabrik
- esde Maschinentechnik
- Fong Kee Iron Works Co.
- Gelaplast
- Gumix, S.A.
- Gebrüder Haake
- Italwork s.a.s.
- Jofra Maschinen
- Killion Extruders
- Kuhne GmbH
- Lenzing AG
- Mai Virginio s.r.l.
- McNeil Akron Repiquet
- Omam S.P.A.
- Omipa S.p.A.
- Plastik-Maschinenbau GmbH
- Plastiprogram s.r.l.
- Prandi G. & C. S.p.A.
- Promatech s.r.l.
- Reifenhäuser GmbH & Co.
- Scamia
- Sentinel Machinery
- Shaw & Co.
- Sherman Treaters Ltd.
- Somaplast snc
- Stealastic
- Tecma Italia S.r.l.
- Toshiba Machine (Europe)
- Troester Maschinenfabrik
- Union off. mecc. s.p.a
- Welex Inc.
- Windmöller & Hölscher
- Woywod Kunststoffmaschinen

Extrusionsanlagen für Mehrschichtfolien und -platten

Extrusion plants for multilayer sheets
Installations de coextrusion
Impianti di coestrusione
Instalaciones de coextrusión

- Achenbach Plastic-Maschinen
- Afex Maschinenbau
- Alpine Aktiengesellschaft, Kunststoffverarbeitungsmaschinen
- Amut S.p.A.
- Axon AB Kunststoffmaschinen
- Bandera Luigi S.p.A.
- Barmag AG
- Berstorff Maschinenbau GmbH
- Betol Machinery Ltd.
- Bielloni Castello
- Bielloni Macchine
- Bielloni S.p.A.
- Breyer GmbH, Maschinenfabrik
- Brückner - Maschinenbau
- Cellier S.A.
- Cincinnati Milacron
- The Cloeren Company
- Colines PP&P S.r.l.
- Colines s.r.l., Gruppo
- Dr. Collin GmbH
- Colmec S.p.A.
- Covema s.p.a., Nuova
- Dalaker Kunststoffmaschinen
- Davis-Standard
- Dipiemme Dies
- Dolci S.p.A., Ing. L.
- Egan Machinery Division
- ER-WE-PA Maschinenfabrik
- Extrudaids Limited
- Fairex
- Falcon
- Fong Kee Iron Works Co.
- Friul Filiere s.r.l.
- Gimac di Maccagnan
- Gumix, S.A.
- Gebrüder Haake
- Indemo S.A.
- Italwork s.a.s.
- Jofra Maschinen
- Kiefel Extrusionstechnik
- Killion Extruders
- Kuhne GmbH
- Lenzing AG
- Macchi S.R.L.
- Macro Engineering
- Mai Virginio s.r.l.
- McNeil Akron Repiquet
- Oleotti, Pio
- Olmas S.R.L.
- Omam S.P.A.
- Omicron Plann s.r.l.
- Omipa S.p.A.
- O.M.V. - Officine
- Plastik-Maschinenbau GmbH
- Plastiprogram s.r.l.
- Prandi G. & C. S.p.A.
- Reifenhäuser GmbH & Co.
- Scamia
- Sentinel Machinery
- Shaw & Co.
- Sherman Treaters Ltd.
- Somaplast snc
- Tecma Italia S.r.l.
- Tecom S.r.l.
- Toshiba Machine (Europe)
- Union off. mecc. s.p.a
- Welex Inc.
- Western Polymer Division
- Windmöller & Hölscher
- Woywod Kunststoffmaschinen

Extrusion plants for tubular films

Installations d'extrusion de gaines
  soufflées
Impianti di estrusione per film e foglie
  tubolari
Instalaciones de extrusión para lámina
  tubulares

Afex Maschinenbau
AISA Automation Industrielle
Alpine Aktiengesellschaft.
  Kunststoffverarbeitungs-
  maschinen
Amut S.p.A.
Angelo Ciola e Filhos
APV Chemical Machinery
  Limited
Arvor GmbH
Axon AB Kunststoffmaschinen
Bandera Luigi S.p.A.
Barmag AG
Bassani Mascheroni & C Srl
Battenfeld Extrusionstechnik
Battenfeld Gloenco
Betol Machinery Ltd.
Bielloni Castello
Bielloni Macchine
Bielloni S.p.A.
Brampton Engineering Inc.
Carnevalli + Cia
Carvalho & Catarro, S.A.
Cincinnati Milacron
Cogemi s.r.l.
Dr. Collin GmbH
Cosmoplastics S.p.A.
Dalaker Kunststoffmaschinen
Davis-Standard
Davis-Standard
Dolci S.p.A., Ing. L.
Egan Machinery Division
Extrudaids Limited
Fairex
Falcon
Fong Kee Iron Works Co.
Formac s.r.l.
Future Design Inc.
Garant Maschinenhandel
Gumix, S.A.
Gebrüder Haake
Herlan & Co
Indemo S.A.
Italwork s.a.s.
Jofra Maschinen
Kiefel Extrusionstechnik
Killion Extruders
Kuhne GmbH
Lenzing AG
Macchi S.R.L.
Machinery Bellora
Macro Engineering
M.A.M. - Meccanica
Meccaniche Moderne
Omicron Plann s.r.l.
Placo Co., Ltd.
Plastik-Maschinenbau GmbH
Plastimac S.p.A.
Plastiprogram s.r.l.
Prandi G. & C. S.p.A.
Reifenhäuser GmbH & Co.
Reinhold, Klaus
Scamia
Sherman Treaters Ltd.
Taiwan Universal Ltd.
Tecma Italia S.r.l.
Tecom S.r.l.
Western Polymer Division
Windmöller & Hölscher
WMW-Export-Import
Zeta Plastic Sales

Extrusionswerkzeuge
Extrusion dies
Filières d'extrusion
Filiere per estrusione
Moldes de extrusión

actual Anlagen-, Maschinen- und Werkzeugbau
Alpine Aktiengesellschaft, Kunststoffverarbeitungsmaschinen
Ameg AG
Amut S.p.A.
APV Chemical Machinery Limited
Axon AB Kunststoffmaschinen
Bandera Luigi S.p.A.
Barmag AG
Battenfeld Extrusionstechnik
BemaTec SA
Berstorff Maschinenbau GmbH
Bestenlehrer GmbH
Betol Machinery Ltd.
Böhler Ges.m.b.H.
Brabor s.r.l.
Braun Werkzeugbau GmbH
Breyer GmbH, Maschinenfabrik
Brügmann Frisoplast GmbH
B & S Gereedschappenindustrie
Calcagni Mario & C.
Campagner Angelo
Cincinnati Milacron
The Cloeren Company
Colines PP&P S.r.l.
Colines s.r.l., Gruppo
Corma Inc
Covema s.p.a., Nuova
Davis-Standard
Davis-Standard
Dipiemme Dies
Entex Rust & Mitschke
ERE Kunststoff
esde Maschinentechnik
Eubel KG, W.
Extrusion Dies Inc.
Facit & Incorporation
Formplast Möller
Fränkische Rohrwerke
Friul Filiere s.r.l.
Future Design Inc.
The Gauge and Tool Makers Association
Gillard & Co. Ltd.
Hassenzahl Sohn GmbH
Hauzer Techno Coating
Hawo Metaalbewerking b.v.
Hivet ECM
Ide, Bernhard
Industrie Generali Group
Komeetstaal A.E.E. Merk
Krupp Bellaplast
Krupp Maschinentechnik
KUAG - Kunststoffmaschinen
Macro Engineering
Mai Virginio s.r.l.
Maplan International
Mirotech Inc.
Molde Matos
Müller + Sohn AG, Paul
Müller ratiolab
Nokia - Maillefer
O.C.F.
Oleotti, Pio
Omipa S.p.A.
Picard GmbH & Co. KG, C. A.
Previero N. S.r.l.
R C M AG, Rubber Consulting + Machinery
Rotfil s.r.l.
Shaw & Co.
Soarmoldes
Somaplast snc
Somoplaste
Techno-Chemie Kessler
Technoplast Kunststofftechnik
Tecma Italia S.r.l.
Theysohn Maschinenbau
Theysohn-Extrusionstechnik
Thyssen Edelstahlwerke
Truplast Kunststofftechnik
Uni-Flo
Uniplast Kunststofftechnik
Verbruggen p.v.b.a.
Vollmar Anlagentechnik

Blaswerkzeuge
Blow moulding tools
Moules de soufflage
Stampi per soffiaggio
Moldes de soplado

A.D.S. S.A.
Aspoh House
Barmag AG
Battenfeld Fischer
Bekum Maschinenfabriken GmbH
Bemaco Maschinenbau GmbH
Böhler AG
Bredlow GmbH
B & S Gereedschappenindustrie
Eder, Karl, Robust-Plastik
Eubel KG, W.
Facit & Incorporation
Falcon
Foboha GmbH Formenbau
Formplast Möller
The Gauge and Tool Makers Association
Gerstung Modellbau KG
GIEMO
Hass GmbH & Co.
Hawo Metaalbewerking b.v.
HEK GmbH
Hivet ECM
Holloway
Industrial Santa Rosa
Italstampi srl
Jacob GmbH, Harry
Johnson Controls
Köbelin-Werkzeugbau
Krupp Kautex
Kunststofftechnik Waidhofen
Lamko Tool & Mold
Lips B.V.
Luger Formenbau
Magic MP S.p.A.
Mat Plast Sarl
Mauser-Werke GmbH
Mirotech Inc.
Moldoplástico, Lda.
Moulds Point S.R.L.
Müller GmbH, W.
PEC GmbH
Perstorp Compounds
Planimolde
Poltec
PPK Plastic Project
Rotfil s.r.l.
Ryka Blow Molds Ltd.
Sate System S.r.l.
Sermo S.A.
Sidel
Soltauer Zinngießerei
Stahl Blasformtechnik
Standex International
TEA - Berto Lamet
Thyssen Edelstahlwerke
Torbay Engineering Co.
Uniloy Comec
Uniloy Moretti
Wentworth Mould and Die
Wieser Maschinenbau

Measuring equipment for material testing
Appareils de mesure pour l'essai des matériaux
Apparecchiature di misura per prove su materiali
Aparatos de medida para ensayos de materiales

ATS FAAR S.p.A.
Brabender OHG
Ceast S.p.A.
Coesfeld GmbH
Comago s.r.l.
Dubuit, Machines Dubuit
Eekoner Industrial Co., Ltd.
Electrolux Systemtechnik
Electronic Systems S.p.A.
Elektro-Physik Köln
Eltex - Elektrostatik
Erichsen GmbH & Co. KG
Erichsen Vertrieb GmbH
FAG Kugelfischer
Frank GmbH, Karl
Gabo Qualimeter
GEL Instrumente AG
Göttfert
Gebrüder Haake
Hammel Maskinfabrik
Heraeus GmbH, W.C.
Hess Messgeräte
Hillesheim GmbH
Instron International
IPT Institut für Prüftechnik
Kistler Instrumente
Krautkrämer GmbH & Co
Lauda Dr. R. Wobser
Lippke Handels-GmbH
Lloyd Instruments
Macbeth Division
Measurex GmbH
Metravib Instruments
Mettler Instrumente GmbH
Micromet Instruments, Inc.
Mocon/Modern Controls, Inc.
Monsanto Europe S.A.
Myrenne GmbH
Netzsch-Gerätebau GmbH
Octagon Process Technology
OMYA GmbH
Panametrics GmbH
Perkin-Elmer & Co. GmbH
Polymer Laboratories
Rosand Precision Ltd.
Sartorius GmbH
Scantronic Control Systems
Schenck AG, Carl
Dr. Schneider
Schoeller International
Schwing Verfahrenstechnik
Sick GmbH
Simar Fördertechnik GmbH
Solomat Verkaufsbüro
Dr. Stapfer GmbH
Terwin Instruments
Tesch Lascan
Topwave Instruments Oy
UTS Testsysteme GmbH
Well - W. Ebner
Wolpert-Werke GmbH
Zwick GmbH & Co.