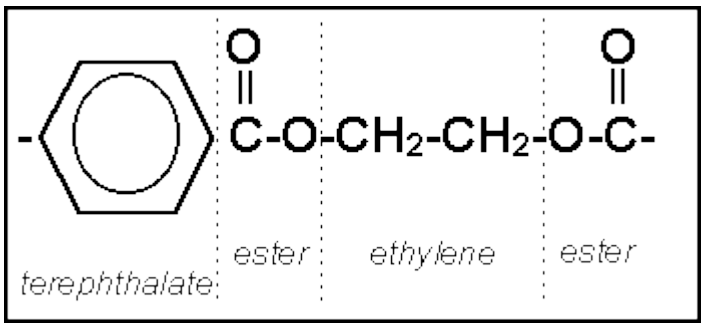
What is PET (PolyEthylene Terephthalate)



PET (also named PETE) is a kind of polyester material for fiber, injection molded parts, as well as blow-molded bottles and jars. Special grades are offered with the required properties for the different applications.

PET is linear thermoplastic (long-chain molecule consists of repeating units shown as figure right), white but bluish resin made from terephthalic acid and ethylene glycol through poly-condensation. PET is supplied by the resin manufacturers in the form of small pellets, each about 0.05 gram. PET came into prominence in the 1950s as a textile material. Its strength, temperature tolerance and wear-resistance made it an ideal replacement for, or addition to natural fibers such as silk, cotton and wool.

It has good antiosmosis, low water absorbability and good toughness. PET film's tensile strength is similar with aluminum film's, and is three times that of PC and PA film. PET film is transparent. It's tensile strength can reach 1/3~1/2 of steel's if dealed by oriented draw. It's the toughest thermoplastic film. It will be burnt with yellow flame and will burst when burning. And it will continue burning when away from fire.

Bottle Grade PET

Nowadays PET is still widely used for these purposes, but when, in the 1970s a marketing need was identified for larger light-weight, unbreakable bottles to contain carbonated drinks, PET fit the bill perfectly. Unlike simple polymers such as polyethylene, PET is not made by a single stage process, but by the reaction between two chemicals, purified terephthalic acid (PTA) and ethylene glycol (EG). The availability of the first of these has dictated the supply of PET resin in the past, but new capacity coming on stream this year will ensure more than adequate supplies to meet the growing uses of PET over the coming years. Related polyesters are polybutylene terephthalate (PBT) used mainly for engineering applications, and polyethylene naphthalate (PEN). The latter offers significant performance improvements over PET, particularly in terms of barrier properties and heat tolerance. Since PEN can be blended with PET a range of new 'alloys' is becoming available for special packaging applications.

As PET (bottle grade) is a kind of transparent, wear-resisting and corrosion-resisting plastics with high strength and smooth finish, it is widely used for PET bottles of mineral water, juice, edible oil, pharmaceuticals, cosmetics, etc.

- **Melting Temperature: 254-256^{0}C**
- **Crystallinity: >=45%**
  PET products can be made crystallizable or non-crystallizable through controlling crystallization temperature and cooling speed. Usually it's crystallinity is 0~50%. The higher IV value, the slower crystallization speed.
  The key factors that effect PET bottles' molding process and performance are crystallization and orientation. If PET's moisture level is high, hydrolysis will happen while molding and it's IV value will drop which means products' quality be affected.

- **Carboxyl End Group: <=20mol/t**
- **Acetaldehyde: <=3ppm** (Ex-Work, related to drying & molding temperature)
  For CSD bottle, <=9ppm required; for mineral water, <=4ppm required.
- **Density: 1.38~1.40g/mm^3**
- **Glass Temperature: 82^{0}C**

In the bottle industry, the length of the PET chains is usually described by the resin IV (Intrinsic Viscosity). Bottle grades have IV values of about 0.65 to 0.85 dL/g, or about 100-155 repeating units per chain.

Most bottle grades of PET are copolymers, which means that a few percent of a modifier has been incorporated into the polymer chain. Copolymers are easier to injection mold because the crystallinity behavior is improved.

A remarkable transformation takes place when injection molded PET is stretched at the right temperatures and to the right extent. The long chains undergo strain-hardening and strain-induced crystallization, which gives the properly-made PET bottle exceptional clarity, resistance to internal pressure, uniform wall thickness, toughness, and a host of other features. To achieve these useful properties, however, care must be taken in choosing the right grade of resin, as well as the right preform and bottle designs, and good molding practices.

Some grades of PET have other modifications to improve the bottle barrier properties, the reheat characteristics (for two-stage systems), or the generation of AA (acetaldehyde).

Main Advantage of PET

- **Crystal Clear**
  Products look good, pure and healthy. Sparkling PET bottles attract attention. Brilliant glass-clear presentation of your products.
- **Pure**
  Products taste good. PET complies with international food contact regulations.

- **Safe**
  PET bottles are tough and virtually unbreakable during production, storage and transportation. If they do fail, they split, not shatter. Their high impact and tensile strength makes them ideal for carbonated products.
- **Good Barrier**
  The low permeability of PET to oxygen, carbon dioxide and water means that it protects and maintains the integrity of products giving a good shelf life. PET also has good chemical resistance.
- **Lightweight**
  10% weight of an equivalent glass pack, PET bottles reduce shipping costs by about 30%, and because the material in the wall is thinner, shelf utilization is improved by 25% on volume compared to glass. High strength, low weight PET bottles can be stacked as high as glass.
- **No Leakage**
  Absolute closure integrity is possible because of the injection molded neck finish. The absence of a weld line in the base means that PET bottles don't leak.
- **Design Flexibility**
  Suitable for containers of all shapes, sizes, neck finishes, designs and colors.
- **Recyclable**
  Excellent environmental profile due to single material. Used PET bottles can be washed, granulated into flakes and reshaped as PET bottles or employed as material for strapping, carpeting, fiber filling, etc. Specially designed thick-wall bottles can be washed, refilled and reused. PET is made from the same three elements (carbon, oxygen, and hydrogen) as paper, and contains no toxic substances. When burned, it produces carbon dioxide gas and water, leaving no toxic residues.
- **Good Resistance**
  PET offers the best chemical resistance performance of any mainstream polymer used in packaging today.
- **Long Shelf-life**
  Very good shelf-life performance, especially with the new higher barrier formulations.

Select the Right Grade of Resin -- Different Resins for Bottles of Different Purpose

Although general-purpose grades are available, as in all walks of life the best results come from a product specifically adapted for its role.

The fact that PET is used for such a variety of packaging items ? from soft drinks to cosmetics ?demonstrates how the qualities of the resin must match the standards needed to keep the product preserved and safe for travel. Not only does the product need to be maintained in good condition, but it also needs to sell. For that reason, the drink or food item and its packaging must be attractive, sensible and convenient. The resin chosen for a certain PET application has to fulfil the requirements of the end product. Strength, clarity, barrier performance and UV resistance are only a few of the factors to be considered in packaging.

Homopolymers and copolymers are both used in PET resins. A homopolymer is PET containing only ethylene glycol and terephthalic acid repeat units which results in the highest melt point and the best strength properties possible. A copolymer is PET containing additional monomers, such as isophthalic acid, to disrupt the polymer chains, resulting in a lower melting point, slower crystallisation and improved clarity particularly in heavy wall applications.

Different grades of resins are appropriate for different end uses. Their specific qualities make them ideal for the product which they have been designed to package. What qualities of PET are important? As mentioned above, the qualities that are important depend very much on the product for which the bottles is destined:

CSD -- Carbonated Soft Drinks

Strength: The resins in PET bottles used to package carbonated soft drinks need very specific qualities. The material must be extremely strong to contain the internal pressures of CO2 without distortion or expansion. This is obtained by using a resin which has high IV and lower copolymer levels.

Clarity: Clarity is an important aspect of drink packaging in terms of consumer

acceptance. A low level of crystallisation is needed to achieve clarity.

Colour: Although one of the key qualities of PET is that it can be used as a perfectly clear material, with soft drinks this property is not essential as many soft drinks themselves are coloured, while clear soft drinks are packaged in coloured PET bottles.

Water -- The Clear Story

Some waters are packaged in exactly the same bottles as carbonated soft drinks and would therefore carry many of the same requirements, but some vary.

Strength: Unlike carbonated drinks, the bottle filled with still water needs only enough strength to hold water and to survive impact. IV requirement is reduced to the .74 to .76 range in most cases.

Colour and Clarity: Clarity is one of the most important reasons why PET is used for packaging water. PET used in water bottles needs to be very clear and maybe even slightly blue in colour. A resin with higher levels of copolymer adds to the clarity.

Purity: Because water is a flavourless product, having a plastic that remains tasteless and odourless is imperative. In general terms PET doesn't affect the taste of the product it protects and therefore is a key material for packaging water.

Juice -- Hot Fill Qualities

Juices and many other products such as sport drinks or other high acid drinks are hot filled into PET bottles. In these cases the package is heat set in order to improve the temperature resistance of the container. PET resins with a higher Tg (glass transition) temperature and/or a faster rate of crystallisation are preferred. Generally lower levels of copolymer are preferred and IV's of about .80 are acceptable.

Strength and colour/clarity: This factor is not as important with juices as CSD's or water. The purity factor is important, as juices would contract the taste of the plastic bottle if not pure enough.

Beer -- A New Market with New Requirements

Beer is often seen as an extension of the CSD market, but also often requires heat fill and barrier qualities. Because the technologies used to make beer bottles are varied and the applications differ (cold filled or pasteurised), finding a common denominator is difficult. Making a bottle to meet the desired requirements has been the most important factor. The types of PET beer bottles typically used are: non-tunnel pasteurised, one way tunnel pasteurised and returnable/refillable bottles.

Barrier: Beer needs higher performance in both CO2 and O2 barriers compared to PET used in CSD applications. The level required depends on the type of beer, container size, distribution channels and environmental conditions (storage time, temperature and humidity levels). Improvements in barrier properties can be obtained via coatings, creating mutli-layer bottles and scavengers.

Colour, clarity and UV protection: Beyond the barrier properties, most beers also need to be protected from UV light. Protection can be obtained via colorants or UV additives, which can be added to the PET at the injection stage. Because of the varied requirements for beer, resins must be chosen which provide an adequate barrier, UV protection and clarity.

Strength: Beer bottles do need strength in order to maintain the CO2 pressure over a wide range of temperatures including pasteurisation. IV's in the .80 to .84 range are normally favoured. Beer bottles also tend to use champagne bases rather than footed or "petaloid? bases. In all of the above cases, the resource efficiency

of PET - due to its light weight - is one of the essential reasons why it is used with these consumer drink products. Not only does the consumer benefit, but the transportation costs and energy consumption in delivery are decreased due to its weight. Because PET bottles are so much lighter than alternatives, a truck can carry 60% more of the beverage and 80% less packaging ?a fuel saving of 40% and less air pollution.

To Produce PET Preform/Bottle

Traditionally PET bottle molding machines could be divided into two categories - those using the One-Step "hot preform" method and those using the Two-Step "cold preform" method.

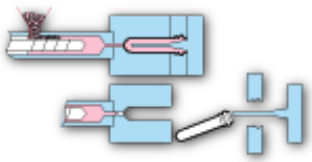
The One-Step method -- from PET granule to finished bottle -- all processes are completed on one integrated machine. This means the injection-molded preform is withdrawn from the injection cavity while still hot enough to be stretch blown to form the bottle. No extra heating is required, and since preforms are not stockpiled to be blown at a later date, but are freshly molded every time, there is no risk of surface damage from preforms knocking together during storage or transportation. One-Step method is highly suited to small and medium scale production lines.

The Two-Step method uses two separate machines. The preform is injection molded on the first, then reheated and blown on the second. The Two-Step system uses two separate machines: an injection molding machine for making the preforms, and a reheat blow molding machine to reheat the preforms from cold and blow the bottles. The requirement for a preform heating system means the Two-Step process has a lower thermal efficiency. This method is most suited to medium to large-scale production.

Usually 2-stage method is adopted to produce PET bottle.

- **Drying of PET**
  PET absorbs moisture from the atmosphere. This must be removed by a dehumidifying drying before processing.

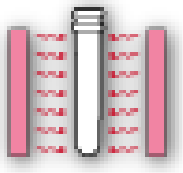
- **Plasticizing the PET**
  Dried PET pellets are compressed and melted by a rotating screw.



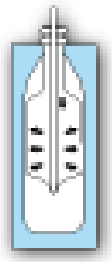
- **Injection Molding the PET Preform**
  Molten PET is injected into the injection cavity and cooled rapidly to form a "preform? (The

test-tube-like form from which bottles are blown is known as a preform).
For more information, click here.

- **Heating the PET Preform**
  The temperature of the preform is adjusted to the correct profile for blowing.



- **Stretch Blow Molding the PET Container**
  The hot preform is simultaneously stretched and blown (thereby orienting the crystals of and strengthening the PET*) into a shaped blow mold to form a tough, lightweight container. PET that is heated to a temperature where its chain-like molecules are sufficiently mobile to uncoil instead of breaking when extended, can be oriented by stretching. Stretching applied from two directions at right angles, as in stretch blow molding, gives biaxial orientation. Oriented PET contains closely packed chains aligned in the directions of stretch. The material is stronger because the molecules act together instead of individually. The tensile strength of oriented PET is several times that of the unstretched material and the impact strength, barrier and chemical resistance are also significantly improved, so bottles can be lighter without sacrificing performance.
  For more information, click here.



- **PET Container Ejector**
  The finished container is ejected.

Acetaldehyde Level

What is Acetaldehyde? Acetaldehyde (AA) is a compound that exists naturally in many citrus fruits and other foods. It has a distinctive acidic taste. Acetaldehyde is also generated during the process of PET bottle manufacture.

How Acetaldehyde affects the product? With the growing popularity of PET containers, water companies are becoming more aware of AA and how it can affect product taste. In most cases, the flavour of AA is barely

detectable during beverage consumption. Carbonated soft drinks, for example, have very sweet or tangy flavours that mask the slight taste of the plastic. But the very delicate, or even imperceptible, taste of pure water is not strong enough to mask acetaldehyde, and so it is easier for the consumer to notice the presence of AA. Consumers rank taste as the number one criterion when selecting a water brand. They look for purity that cannot be found in tap water. Water companies retain customer loyalty by delivering consistent, high quality products that fulfil the brand promise. Even minor differences in taste will compromise brand integrity and affect sales.

How is AA generated in PET bottles? During bottle manufacture the resin pellets are dried and melt-processed at high temperatures (higher than 260^0C) and are injection moulded into preforms. The preforms are then reheated and stretch-blow moulded to form a container. It is during the melt-processing stage that AA is generated.

Optimization of the molding conditions by way of **minimizing melt temperature and residence time** can aid in minimizing AA generation. However it cannot be entirely eliminated. AA produced during processing is retained or trapped in the polymer matrix of the bottle or container. Since AA boils at below room temperature, it eventually migrates out of the PET into the atmosphere or into the packaged contents, affecting taste. The amount of AA that migrates is directly related to storage time and temperature. There are a number of ways that AA levels can be significantly reduced so that taste is not affected. The first step is choosing the right PET resin. Resins are available with properties that are specifically tailored to the needs of water containers. For example, Voridian Aqua PET resins 18696 and 20837 are considered leaders in low AA levels. Each has a low intrinsic viscosity (IV) of 0.72 and 0.76 respectively. The low IV minimizes AA generation during melt-processing.

Because bottle performance is important, these resins are designed so that the low molecular weight does not compromise mechanical properties of the finished bottle.

Certain water markets seek AA levels that are lower than even the most progressive polymers will allow. In these cases, the low AA resins are combined with an AA "scavenger? AA scavengers are blended with the PET as it is melted in the injection-moulding phase. The scavenger reacts or combines with AA to 'lock?it into the polymer matrix so that it cannot migrate into the product. Scavengers can further reduce AA levels in preforms up to 70-80%.It is important to choose a PET solution with the proper balance between low AA levels and high performance. This can yield a bottle with excellent mouldability and optical qualities. A low-AA resin should blend well with colors and tinters to produce a package with the look and feel that supports the brand.

To Recycle PET

PET is fully recyclable where facilities exist. It is given the recycling code 1. Post-consumer recycled PET (PCR PET) can be used for clothing and carpet fiber, and fiberfill for stuffing articles such as pillows. Recycled PET can be used to make new bottles for non-food products such as cleaning products. To make food and beverage containers out of PCR PET, it must pass through approved processes to ensure it has no contaminants, and it must retain enough of the original properties to meet the final quality requirements. For more information about recycling PET, check out the NAPCOR website at www.napcor.com.

A simple recycle method popular is to only crush mold PET products, then mix crushed PET granules into virgin PET resins, but the percentage should be no more than 20%. High regrind proportion will cause variance on melt's viscosity, color and odor. Hopper magnet is suggested in injection machine when using recycled material.

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