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Production and Recycling of PET-Bottles

Dr.-Ing. Heino Vest (2003)

Worldwide, PET-bottles more and more replace glass bottles in the beverage and food sector. The success of PET in comparison to glass is based on several economic (and environmental) advantages.

On the one hand, the production of PET is less expensive and energy consuming than the production of glass. Secondly, the light weight of the PET-bottle makes it easier for merchants and consumers to handle the bottles and crates. It saves energy during transport, particularly on long distance haulage. Finally, PET offers more or less the same material properties as glass regarding hygiene, taste and gas impermeability.

The negative impacts of PET-bottles in recent years result from their use as non-returnable beverage containers leading to a dramatic increase of beverage container waste. But even here, changes are on the move, particularly in industrialised countries, where PET-bottles enter more and more the existing returning and refilling schemes. Apart from returning and refilling, recycling of used PET-bottles is also possible, and will be an interesting option especially for developing countries, where refilling schemes are not in place or economically unfavourable.

The following paper offers fundamental information on the production of PET-bottles, recycling options for PET in developing countries and assistance required from government and industry to promote PET recycling.

1. Production of PET-bottles

The material

PET is the abbreviation for polyethylene terephthalate. It is a polyester (chain of individual "ester") which is formed by polycondensation of two types of monomers called ethylene glycol and purified terephthalic acid.

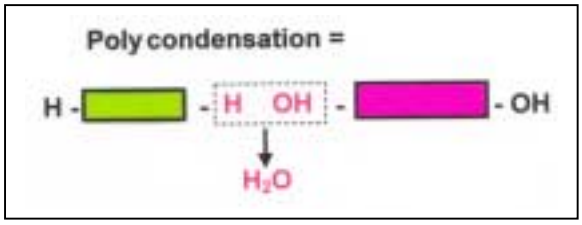

Fig. 1: Principle of polycondensation

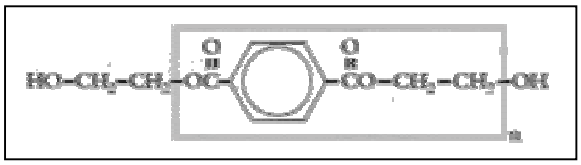

Fig. 2: Polymerisation of PET

It is important to note that during the process of polycondensation water is released. Since the process is reversible, it is important to avoid contact with water during the re-melting of PET (for instance during recycling) as this leads to the decomposing or weakening of the polymer.

PET is produced from either crude oil or natural gas. Approximately 1.9 kg of crude oil are needed to produce 1 kg of PET.

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The overall energy consumption of the PET production is 23 kWh/kg PET. Figure 3 shows the principle of the PET production process.

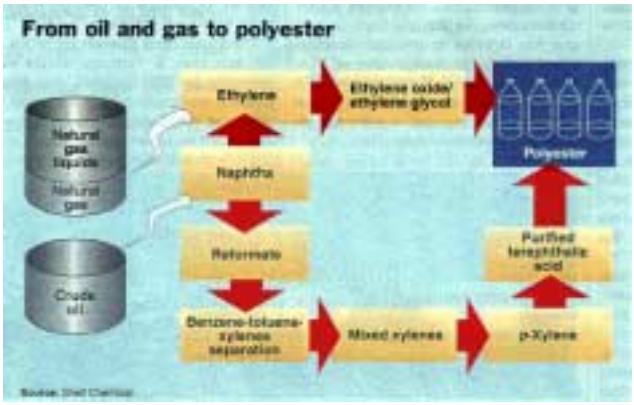

Fig. 3: Production process of PET

PET belongs to the group of thermoplastics, that means, the material is not interlaced (like thermosets) and liquidifies again at higher temperature. Depending on the production temperature PET can be amorphous or crystalline. This results in an opaque or glass clear appearance of the material.

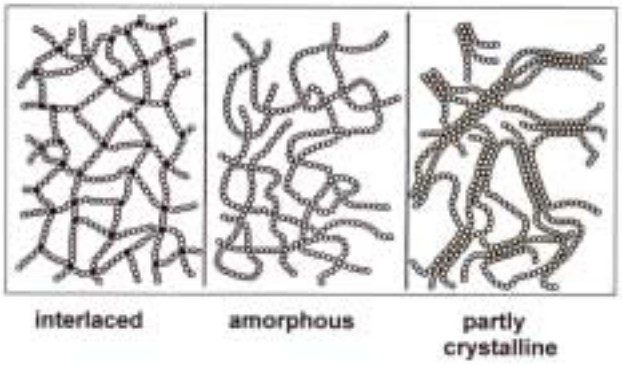

Fig. 4: Different types of polymer structure

Figure 5 and 6 demonstrate the change in transparency due to the amorphous or crystalline structure of PET.

Fig. 5: PET, amorphous

Fig. 6: PET, partly crystalline

Important material properties which determine the production and utilisation of PET are:

- Viscosity: affecting flow behaviour of the material during the manufacturing of bottles
- Glass transition temperature (73-78 °C): indicating the softening point
- Melting temperature (243-250 °C): indicating the liquidifying point
- Crystallising temperature: indicating the change from amorphous to partly crystalline

PET is a suitable material for the production of beverage containers because it is:

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- clear and flexible, but tough
- scatter-resistant
- inert, neutral in taste
- of low weight (1.3-1.33 g/cc)
- recyclable
- with a good gas and moisture barrier.

The higher the grade of crystallisation, the lower the gas permeability.

The History

PET has been well-known under the name of **polyester** for more than 60 years. The development from polyester fibres in the early 1940ies to modern PET bottles is marked by the following milestones:

- 1941: production of first polyester fibres
- 1950s: production of textile fibres (brand names: “Trevira”, “Dralon”)
- 1950-60s: extended use in textile industry

Fig. 5: Polyester fibres

- 1970s: first production of packaging containers
- End of 1980s: first refillable beverage containers

Fig. 6: PET-bottles

Bottle manufacturing process

The manufacturing of bottles from PET primary granules is done in 2 steps:

a) Injection moulding of preforms using standard types of injection moulding machines

Fig. 7: Injection moulded preforms of PET-bottles

b) Blow stretch forming of bottles from preforms

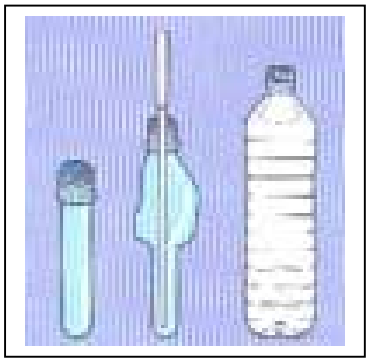

Fig. 8: Blow stretch forming of PET-bottles

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During this process, the preforms are heated to softening temperature in an infrared oven and then are moved to the stretch forming mould. Compressed air is blown through a nozzle into the preform, pressing the soft material to the walls of the mould. After cooling down, the bottle is released from the mould.

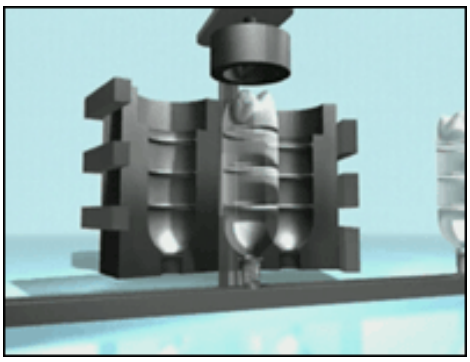

Fig.: 9: Stretch forming mould for PET-bottles

The final stretch forming process usually takes place at the beverage company. Thus only the preforms and not the bulky bottles have to be transported from the PET-producer to the beverage company.

To decrease the gas permeability and to separate recycled plastic from the content, multi-layer bottle are in use. They are produced either from multi-layer preforms or receive an extra layer by plasma deposition after the stretch forming step.

2. Recycling of PET-bottles

Although the percentage of refillable PET-beverage containers increases in Europe and North America, the majority of PET-bottles worldwide are one-way bottles which are discarded after use. PET-bottles contribute increasingly to the generation of waste and litter especially in developing countries. One-way discarded PET-bottles have a negative impact on the environments because they:

- waste resources
- pollute soil, rivers, coastal areas
- pollute the air when burned
- consume a lot of landfill site space
- get scattered and make the environment look untidy.

Recycling of PET-bottles

- saves 65% of the energy for primary PET-production
- offers jobs and income for low income groups.

Depending on the type of raw material three types of recycling are possible:

- Recycling of PET material by re-melting
- Recycling of feedstock material
- Energy recycling

Table 1 describes the preconditions for the different recycling opportunities

Recovery process	Degree of contamination	General economics of the process	Process convenience	Example of feedstocks
Re-melting	Low	Satisfactory	Simple	Refillable PET, One way PET
Partial glycolysis, Glycolysis, Methanolysis, Recovery of TA and EG	Medium	Increasing costs	Increasing complexity	Uncoated heavy guage film, Fibrous waste 100% generic, Coloured PET, Coated PET,
Energy	High	Well established costs	Relatively convenient	Laminates, Coated thin guage film

Tab. 1: Preconditions for the different recycling opportunities of PET-bottle waste

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For developing countries, manual or mechanical beneficiation and re-melting are generally the most appropriate recycling options for PET-bottle waste.

Process steps

Recycling of PET-bottles may include all or some of the following processing steps:

- Collection
  - Returning to supplier
  - Kerbside collection
  - Drop-off locations
  - Buy-back centres
  - Return vending
  - Separation from mixed solid waste
- Sorting
  - Manual positive/negative sorting from mixed waste
  - UV-light assisted sorting
  - automated sorting with optical sensors
- Baling/storage
  - Perforation of bottle
  - Baling, manually or with balers
  - Intermediate storage
- Shredding
  - Wet or dry
- Cleaning, drying, fine separation
  - Washing
  - Float/sink separation
  - Drying
  - Air classifying
  - Electrostatic separation
  - X-ray/optical sorting
- Pelletising (optional)
- Manufacturing to final goods.

Not all of the process steps mentioned above are always needed. Depending on the final product, the requirements of the customer, and the availability of technology and funds the right process step has to be selected. For small scale industry in developing countries, manual or semi-mechanised techniques are most appropriate.

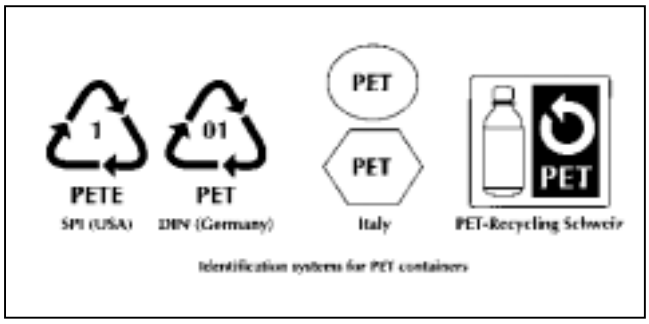

Fig 10: Identification system for PET containers

Fig. 11: Mixed and colour sorted PET-chips(flakes) after shredding, washing and fine separation

Various products can be manufactured from recycled PET-bottles like:

- Textile fibres
- Multi-layer or laminated food-contact containers
- Full-contact food packaging containers (including beverage containers)
- Other applications as shown in figure 12.

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Fig 12: Various items made from recycled PET

Fig. 13: Recycling cycle of PET-bottle waste to new bottles

During the re-melting of PET it is essential that the material, e.g. flakes is completely dry. Due to the reversibility of the polycondensation mechanism, the PET-polymer decomposes if heated in the presence of moisture or water.

Fig. 14: Required number of PET-bottles for various recycling products

During recent years, the recycling of PET, rose steadily (for example in Europe, see Figure 15).

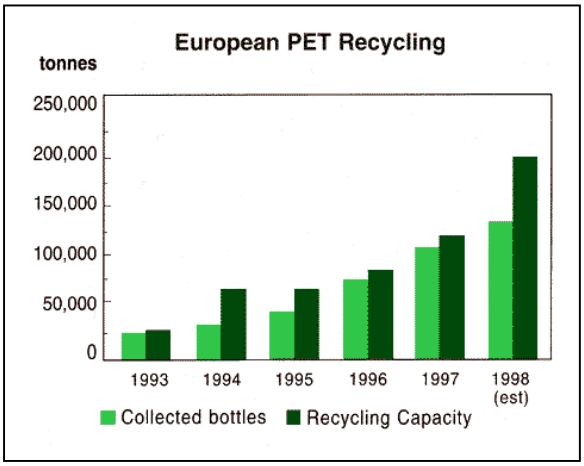

Fig. 15: Recycling of PET in Europe

Recycling of PET-bottles in developing countries

Due to the complexity of the PET re-melting process and the fibre spinning process of polyester, the most successful recycling activities in developing countries are restricted to collection and raw material preparation. These activities are:

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- Collection of PET-bottle waste
- Manual sorting
- Removal of caps and labels
- Perforation and baling
- Shredding
- Washing and drying
- Shipment to customer.

Each upgrading step increases the value of the product.

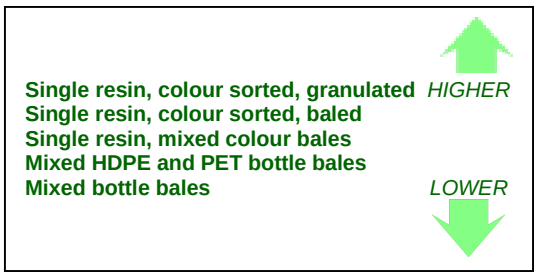


Fig. 16: PET sorting and densification value chain

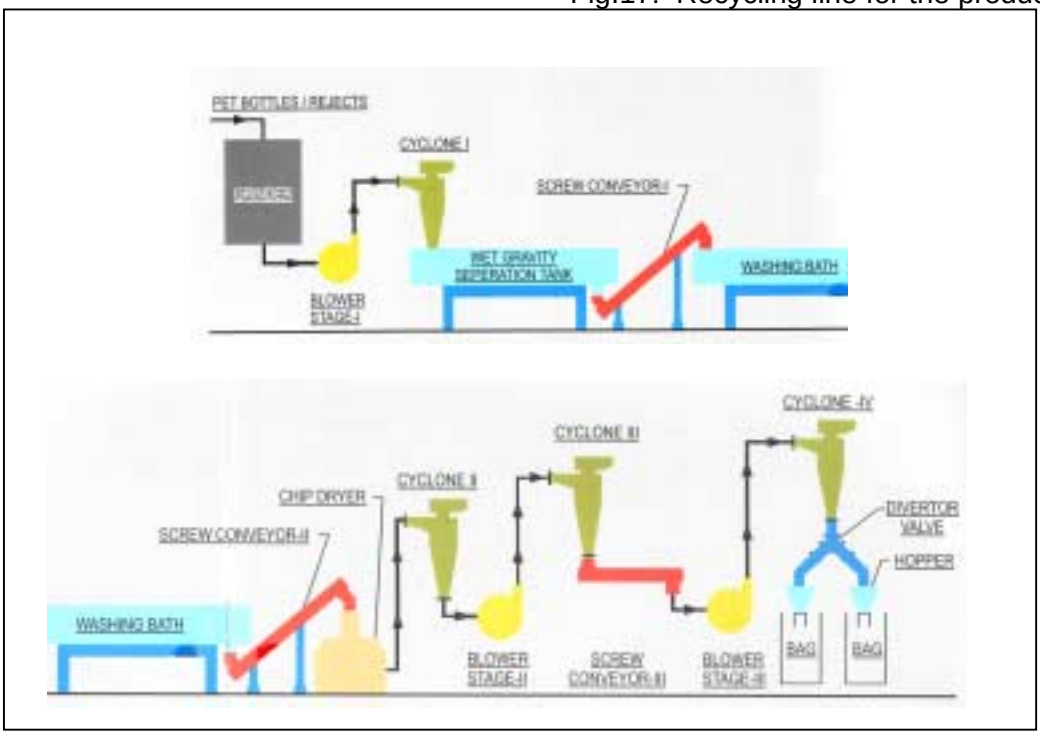
For the above mentioned processing steps, the following machinery would be required:

- Collection vehicle
- Sorting belt
- Perforator
- Baler
- Shredder or cutting mill
- Washing plant
- Drying equipment
- Bagging equipment.

Depending on the size of the operation and the resources available, either manually operated or automated processes are appropriate.

Figure 17 shows an integrated recycling line for PET-bottle waste as it is offered by an Indian manufacturer.

Fig.17: Recycling line for the production of



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The details of the above mentioned production line of a maximum capacity of 500 kg/h include:

- **Components**
  - Granulator (shredder)
  - Wet gravity separation tank
  - Washing bath
  - Chip dryer
  - Several blower stages
  - Several cyclone separators
  - Screw and belt conveyors
  - Hoppers and bagging unit
- **Required utilities**
  - Electric power: 70 kW
  - Compressed air: 10 CFM at 4 to 5 bar
  - Water circulation: 250 LPM at 2-3 bar
  - Water treatment and filtration plant
- **Manufacturer**
  - HIMALAYA Manufacturing Corp., Mumbai, India
- **Price**
  - 176.600 US$, F.O.B. Mumbai, India

There are international standards for the share of contaminants allowed in the various intermediate recycling products, for example:

- **Bales**
  - *allowed contaminants* (e.g. PE, PP, Al, tinplate, paper, coloured PET beverage containers)
  - *prohibited contaminants* (e.g. PET trays, PET-cups, PS, plastic films, wood, glass, stones, oil, grease, hazardous components)

- **Dirty regrind/dirty flakes**
  - *Main contaminants*: PVC, non-PET resins, incompatible PET resins, coloured PET, labels, dirt

- **Clean flakes**

CLEAR PET FLAKE - BOTTLE SPECIFICATIONS

Property	Specification	Test Method
Intrinsic Viscosity (dL/gm)	0.72 - 0.74 min	ASTM D4603
Particle Size (inch)	3/8 - 1/2	Internal
Bulk Density (lbs/ft^3)	18 - 30	ASTM D1895
Moisture Content (%)	< 0.6	Internal
Color	L > 62 b < 3.0	Hunter
Maximum Contaminant Levels (ppm):		
Aluminum	8-10	Internal
Labels	10	Internal
Low Melts	10	Internal
PVC	10 - 25	Internal
EVOH	10	Internal
PP/HDPE	10	Internal
Residual Glue	20	Internal
Green	100 - 1000	Internal

Tab. 2: Clean PET flake specification

For many developing countries the markets for PET-flakes will be outside the country (mainly in industrialised countries). Therefore, the whereabouts of respective customers and suitable marketing lines have to be investigated before starting any recycling operation.

How to develop a nation-wide PET-bottle recycling scheme

A recovery and recycling scheme for used PET-bottles should meet the needs of the population and run with a minimum of administrative procedures. Private sector based income generation through collection and processing of used PET-bottles should be the main driving force. Nevertheless, more parts of the society have to be involved to make PET recycling successful on a nation-wide level:

- Government waste management authorities, municipalities

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- "Waste producers", e.g. PET-bottle suppliers, beverage industry, supermarkets, etc.
- The public, e.g. NGOs, environmental groups, consumer associations, etc.
- The recycling industry, e.g. waste collectors, waste dealers, recyclers.

The focal point of the recovery and recycling scheme can be a preferably non-profit making institution which has to co-ordinate and guide all activities. While collection, processing and marketing should be private sector driven, administrative and financial support would be requested from government institutions.

Common instruments to encourage re-use and recycling are:

- For refillable beverage containers
  - refundable deposit
- For recyclable beverage containers
  - refundable deposit
  - levy surcharge
  - if of high material value

First steps to build up a recovery and recycling scheme for used PET-bottles (as it was discussed during a workshop in Guyana) are:

- **Investigation**
  - Types and quantities of PET-bottle waste
  - Location and needs for transport
  - Required processing and machinery
  - Required man power and training
  - Possible markets
  - Costs and benefits.

- **Planning**
  - Desired involvement of stakeholders
  - Required financing and contributions
  - Design of organisational set-up, possibilities for contracting of partners
  - Needs for training of staff and education of public.

- **Implementation**
  - Set-up a co-ordinating body
  - Securing the financial structure
  - Set-up a collection system involving private partners
  - Set-up waste processing plants
  - Training and education
  - Marketing.

- **Monitoring**
  - Collection system, recovery rates
  - Processing, product quality
  - Marketing, revenues from sales
  - Administration, performance of whole system
  - Finances, sustainability of system
  - Needs for adjustments.

Within the recovery and recycling scheme the various stakeholders have different responsibilities and duties.

The **co-ordinating body** may be formed by

- the beverage industry, or
- an NGO, or
- government bodies, or
- private entrepreneurs, or
- a consortium of several stakeholders.

Its duties include:

- Set-up of a central buyback centre for used PET-bottle
- Promotion of regional buyback centres
- Organisation of transport of collected used PET-bottles
- Set-up of a central processing plant for used PET-bottles
- Promotion of privately operated processing plants
- Marketing of processed and unprocessed used PET-bottles
- training and education of small scale recyclers and the public.

Partners in the waste management sector, supporting the various activities are:

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- Municipalities, cleansing departments
- Private waste management companies
- Small scale waste pickers and recyclers
- NGOs, charity organisations, schools
- Private homes.

Financing may come through
- Contribution of beverage industry, or
- Government subsidiaries, or
- Levy, refundable deposit, or
- Sales revenues, or
- A combination of all

Supervision may take place through
- Ministry of Health or other responsible ministries
- Governmental waste management authorities
- NGOs, such as consumer and environmental organisations

Further information is available under:

- **www.americanplasticscouncil.com**
- **www.handsonplastics.com**
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- **www.cwc.org**
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