

## Polyethylene Terephthalate

*Process Technology (including Comparison of Alternative and Emerging PET Processes, such as Eastman's IntegRex process), Production Costs, and Regional Supply/Demand Forecasts are presented.*

PERP07/08-5

Report Abstract

April 2009

# CHEMSYSTEMS PERP PROGRAM

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## INTRODUCTION

The Polyethylene terephthalate (PET) fiber market over the last decade has been characterized by a boom in East Asia and bust in most other areas. Older plants in higher cost areas in the West have been gradually driven out of production by modern, highly competitive producers in East Asia. Within East Asia, producers in Japan, South Korea, and Taiwan themselves face competitive pressure from the snowballing industry in China, which benefits from lower labor cost, and now accounts for just over half of global polyester fiber production.

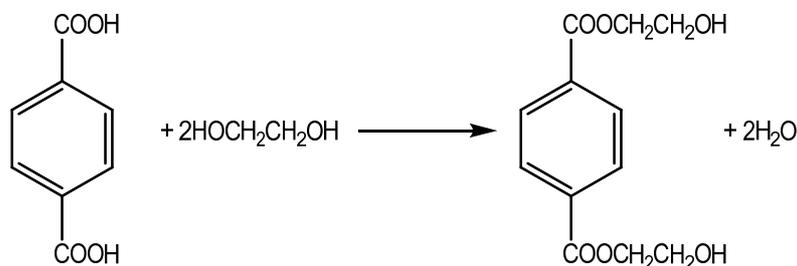
PET may be produced from ethylene glycol and either dimethyl terephthalate (DMT) or terephthalic acid. High purity is required of all raw materials. In either case, the first step of the reaction is the formation of a prepolymer, bis-hydroxyethyl terephthalate (bis-HET). Subsequent polymerization of this material (with the removal of ethylene glycol) forms the polymeric polyethylene terephthalate. The extent of polymerization (apparent from the molecular weight of the polymer) is a function of the polymerization conditions and significantly affects the properties of the resin that is produced.

## COMMERCIALY AVAILABLE TECHNOLOGY

Until the mid-1960s, DMT had been the preferred feedstock for PET manufacture, partly because the ester could generally be made in purer form than the acid. With the development of high-purity terephthalic acid processes, notably by Amoco, the free acid gained acceptance and is now the preferred feedstock. The use of high purity terephthalic acid (purified terephthalic acid - PTA) eliminates the need to recover or recycle methanol and has the added advantage that esterification to the prepolymer is considerably more rapid than the transesterification reaction, which is the first step when starting from DMT. Since the DMT process is still in commercial use, its chemistry is included in this report; however, no process description or economics are presented.

### Conventional Melt/Ssp Technology

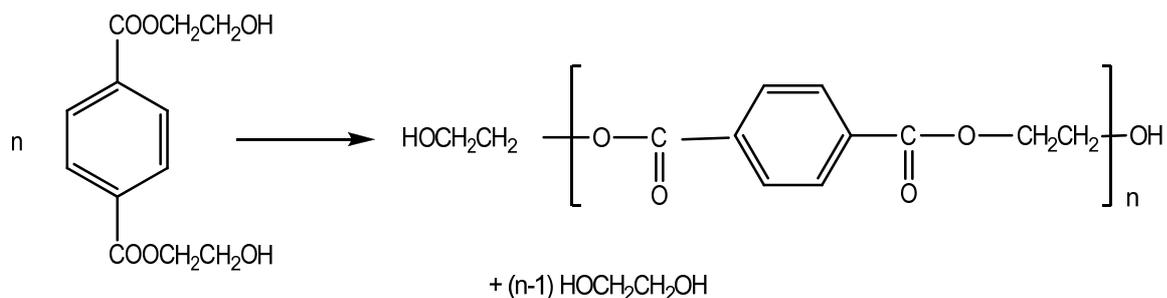
When starting with terephthalic acid (TPA), the first step in the polymerization sequence is an esterification rather than a transesterification:



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Note that water, rather than methanol, is liberated in the process, which simplifies the recovery facilities. The major breakthrough in the technology of this reaction involved operating at pressures above atmospheric and temperatures greater than the normal boiling point of glycol, to achieve shorter reaction times.

Whether TPA or DMT is the starting material, the second step in the polymerization sequence, polycondensation of bishydroxyethyl terephthalate, is the same.



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### Process Description

The conventional PET process consists of two discrete plant sections; the melt phase reaction to lower intrinsic viscosity product that is suitable for textile applications, but not for bottle grade and other high molecular weight applications. That lower intrinsic viscosity material is then further polymerized to bottle-grade intrinsic viscosity in a solid-state polymerization section. [Note that intrinsic viscosity (as well as molecular weight) indicates the degree of polymerization, which in turn is the main factor in setting the properties of PET.]

- A flow sheet for a typical generic continuous PTA-based bis-HET process is given, including provisions for the optional feeding of comonomers such as IPA (isophthalic acid), CHDM (cyclohexane dimethanol), and DEG (diethylene glycol), as well as a brief description of the esterification of PTA to bis-HET.
- A process flow sheet for the polycondensation system is presented, as well as a brief description of this section of the process.
- The polymer chips from the polycondensation step are further polymerized in the solid-state to yield PET chips with higher intrinsic viscosities. A process flow sheet and brief description for continuous solid-state polymerization is presented.
- A flowsheet and brief description for the purification of the byproduct ethylene glycol is given.

## ALTERNATIVE COMMERCIAL PROCESSES

### Uhde Inventa-Fischer MTR

Uhde Inventa-Fischer (UIF) offers what they claim is the latest proven technology based on its innovative 2-reactor technology for the polyester polycondensation. The newly developed melt to preform (MTP<sup>®</sup>), melt to resin (MTR<sup>®</sup>) process is claimed to significantly reduce the production costs for preforms or bottle grade chips. The design features their DISCAGE<sup>®</sup> Finisher, which handles the required medium and high-viscosity polymer without further solid stating.

- A process description and simplified process flow diagram of the UIF 2R process for bottle-resin chips is presented
- UIF's Two-Reactor technology can also be designed to produce resin directly to preforms (MTP<sup>®</sup>). A brief description and sketch of the MTP<sup>®</sup> process is given, as well as a schematic showing the plant configuration for a 100 thousand metric ton per year plant with details of the preform machines.

### Aquafil/Buhler S-HIP Combined Design

The combination of melt phase (CP) and solid-state polycondensation (SSP) in the production of PET bottles has proven to be a technically reliable and commercially successful technology. SSP is the best way to achieve PET bottles with low levels of acetaldehyde. The new S-HIP process (Solid High-Intrinsic Viscosity Polycondensation) improves on conventional technology by shifting the process balance away from CP toward SSP.

- The CP/S-HIP concept is described and schematically illustrated.
- For PET resin, the Aquafil 1-reactor melt design is proposed to feed a section than can further polymerize the polyester to a final PET bottle resin intrinsic viscosity level. This arrangement is described and illustrated.

### M&G EasyUp<sup>™</sup>

M&G has developed an SSP technology improvement called EasyUp<sup>™</sup> that it claims simplifies the process and the plant layout, lowering both the capital cost and the operating cost.

- A brief comparison between EasyUp<sup>™</sup> and conventional technology is presented in tabulated form.

### Zimmer DHI (Direct High Intrinsic Viscosity Process)

Lurgi Zimmer has developed a process called the Direct High Intrinsic Viscosity Process (DHI) that eliminates solid stating (SSP) and the production of melt chips.

- The Lurgi Zimmer DHI Four Reactor Configuration is described and illustrated schematically.
- Capital and raw material costs comparison with conventional plant (melt phase plus SSP) is briefly presented in tabulated form.

## EMERGING TECHNOLOGY

### Eastman Integrex™

Eastman recently announced an innovation in the polyester chain called *IntegRex™*, that promises savings compared to conventional *para*-xylene to polyester resin technology. Eastman has built a 350 000 metric ton integrated PET manufacturing facility using this new technology.

- The process is described with schematic illustrations

## ECONOMICS

Cost of production estimates for the following are presented:

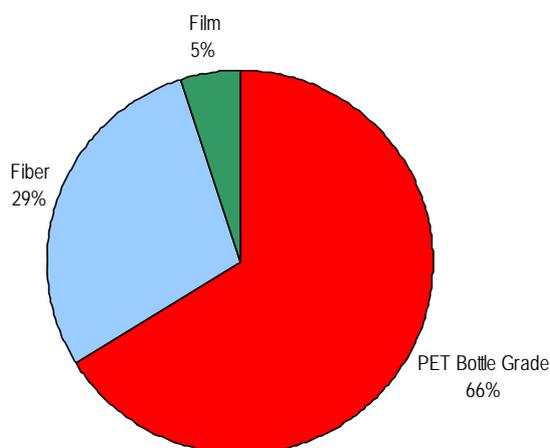
- Production of melt-phase PET resin from conventional technology
- Production of PET resin by the combined Aquafil melt/Buhler S-HIP SSP processes
- Production of PET resin by the UIF MTR process
- Production of PET resin by the Lurgi Zimmer DHI process
- Nexant has incorporated the suggested Eastman developments into an estimated, grass-roots PET plant. Nexant has examined two cases:
  1. A stand-alone *IntegRex™* PET plant with the pipe-reactor design, and
  2. A pipe-reactor PET plant integrated with a PTA plant (Eastman's EPTA technology) with improvements cited in patents.

## COMMERCIAL ANALYSIS

Fiber producers have for some time been converting older plants to PET bottle grade production by adding SSP capacity, in order to escape the more difficult market conditions in the fibers industry. This is still ongoing in certain areas, although the amount of remaining capacity that could be converted to competitive PET resin capacity is minimal relative to the amount of new capacity expected.

Considering the United States, PET Melt Phase has two major outlets: PET resin for packaging applications and polyester fiber for textiles. PET resin, or bottle grade, is one of the fastest growing plastics markets. Polyester fiber is the second largest segment, but the market is mature. The third use, film, is also a mature market, as shown in the Figure below.

U.S. PET Consumption by Derivative, 2008  
(Weight percent)



Q109\_00101.0008.4105\_Charts.xls\Figure 5.1

- Tables giving extensive listings of PET melt capacity by specific plant, location, company and process are given
- Supply and demand trade data are given and briefly discussed for the United States, Western Europe, and China



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