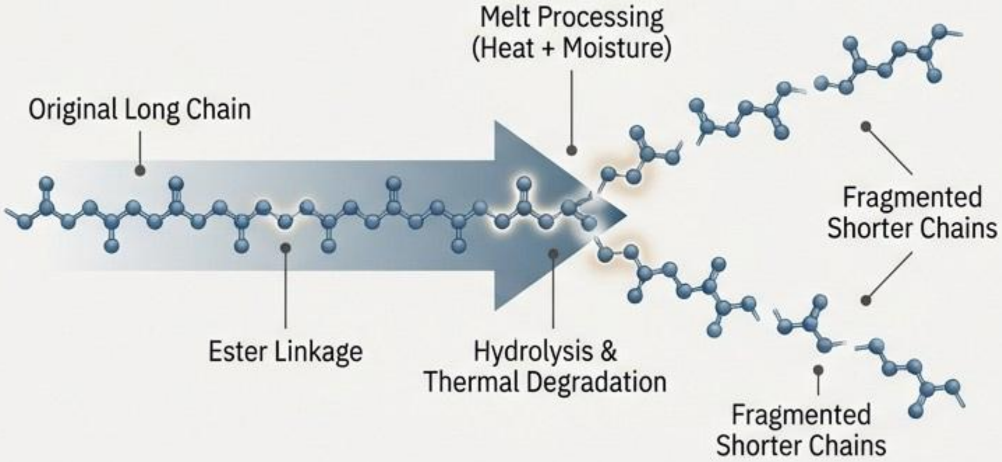
The Reinvention of a Polymer

A Strategic Overview of Viscosity Enhancement Technologies for High-Value Recycled PET

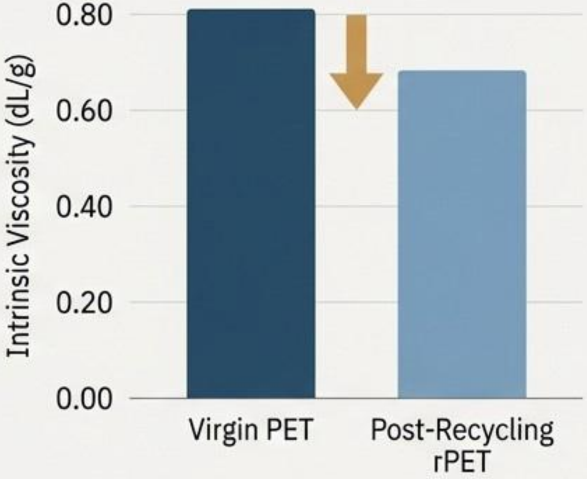
BOXIN

The Inevitable Challenge: Molecular Degradation in Conventional Recycling

Every melt-processing cycle severs PET's long molecular chains through hydrolysis and thermal degradation. This fundamentally reduces its Intrinsic Viscosity (IV), a critical measure of molecular weight and mechanical strength.



Degradation's Impact on IV



Conventional recycling typically causes an IV drop of **0.05 - 0.15 dL/g**. This degradation limits rPET to lower-value applications, preventing true circularity for high-performance products.

The Mission: Rebuilding Molecular Weight to Unlock Value

The key to upgrading rPET is to reverse the degradation by increasing its Intrinsic Viscosity. This is achieved through polycondensation reactions that re-join polymer chains, increasing their length and restoring mechanical performance. Two primary industrial pathways exist to achieve this.

Solid-State Polycondensation (SSP)

Processing below the polymer's melting point. The mature, high-volume industry standard.

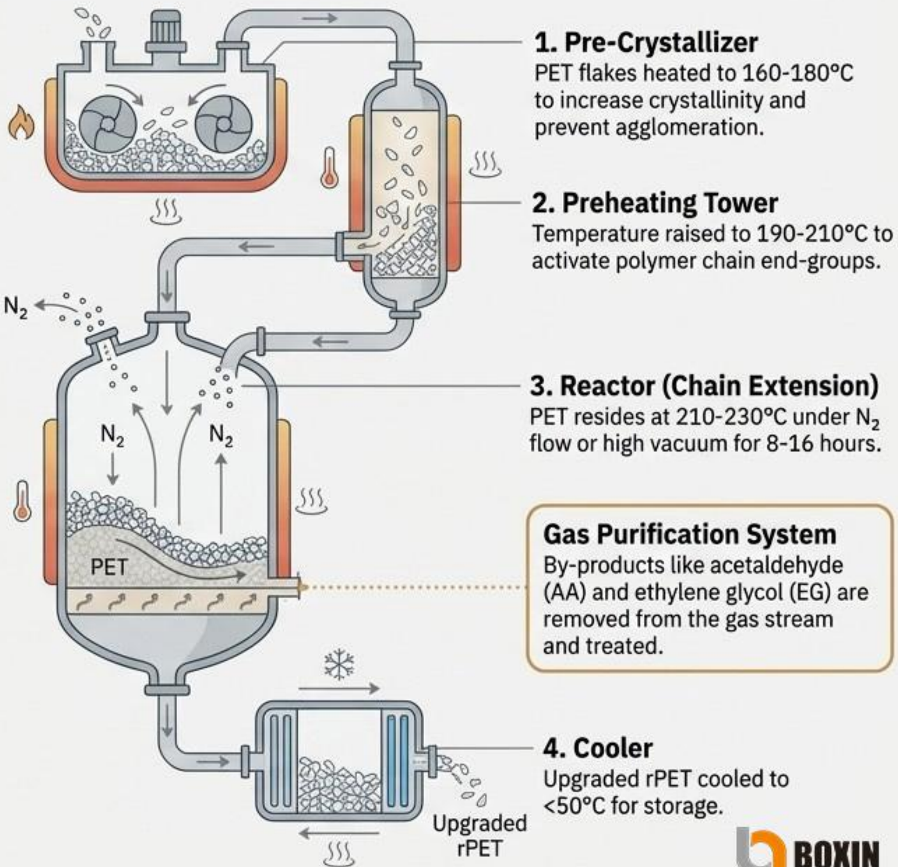
Liquid-State Polycondensation (LSP) & Reactive Extrusion

Processing in the molten state. The high-performance path for specialized applications and advanced materials.

The Industrial Workhorse: Solid-State Polycondensation (SSP)

The Principle

SSP is a process where low-IV PET particles (chips/flakes) are heated to a temperature above their glass transition point but below their melting point. In an inert gas or vacuum environment, residual glycols and water are removed, driving a polycondensation reaction that extends the polymer chains.



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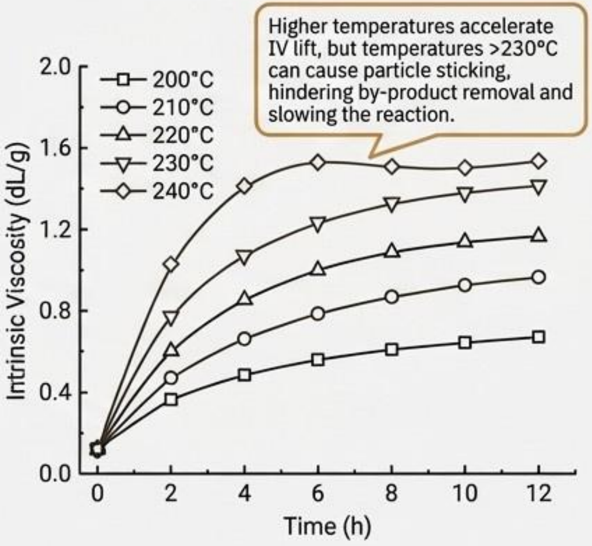
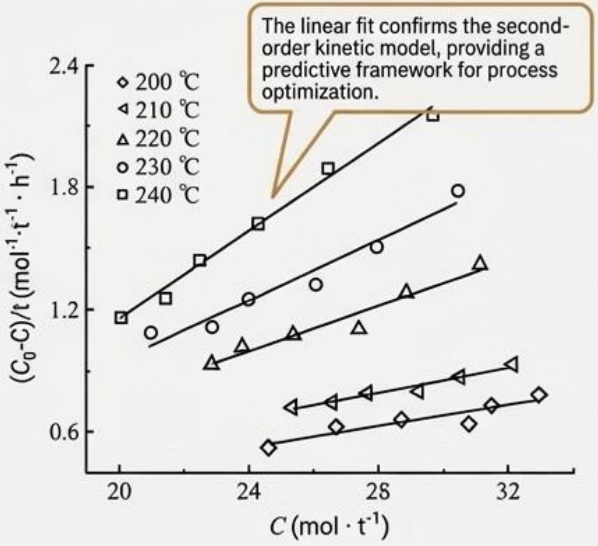
The Engine Room: Proving the Second-Order Kinetics of SSP

Academic studies confirm that SSP follows a modified second-order reaction model, where the reaction rate is dependent on the concentration of 'active' chain end-groups in the amorphous regions of the polymer. The process is a careful balance between reaction rate and by-product diffusion.

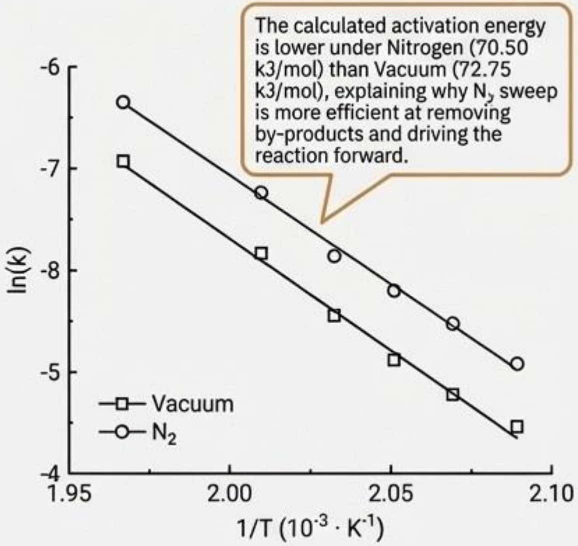
IV vs. Time & Temperature



Kinetic Model Fit



Arrhenius Plot: N_2 vs. Vacuum



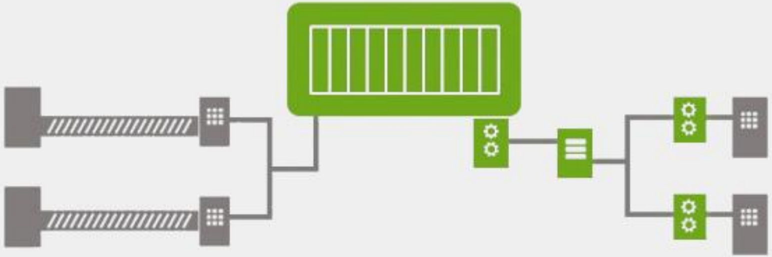
BOXIN

The High-Performance Path: Liquid-State & Reactive Upgrading

The Principle

Unlike SSP, these technologies operate above PET's melting point (typically 275-295°C), performing the polycondensation reaction in the liquid phase.

This environment allows for faster reaction times and the potential to achieve. significantly higher intrinsic Viscosities.



Liquid State Polycondensation

This approach is essential for applications demanding exceptional strength and performance, capable of pushing IV well beyond 1.0 dL/g.

BOXIN

A Spectrum of Advanced Liquid-State Technologies

Batch Reactor Systems

Inter Semi-Bold

A series of stirred-tank reactors operating under high vacuum (<1 mbar). The extended residence time (2-4 hours) allows for significant IV lift, reaching up to 1.2 dL/g.

IBM Plex Sans Medium

Best For: High-IV specialty polymers where batch consistency is key.

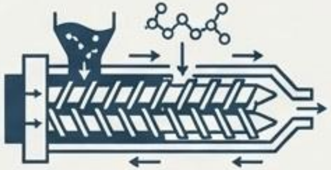
Thin-Film Reactors

Inter Semi-Bold

The molten polymer is spread into a thin film to maximize surface area, drastically improving mass transfer and the removal of reaction by-products. This shortens reaction time to 30-60 minutes.

IBM Plex Sans Medium

Key Example: The Barmag Discage reactor is a leading commercial example of this principle.



Reactive Extrusion

Inter Semi-Bold

A highly flexible process performed in a specialized twin-screw extruder. Chain extenders (e.g., epoxies, oxazolines, anhydrides like PMDA) are added to the melt, rapidly “stitching” PET molecules together.

IBM Plex Sans Medium

Best For: Compounding, creating polymer alloys, and producing smaller batches of tailored materials.

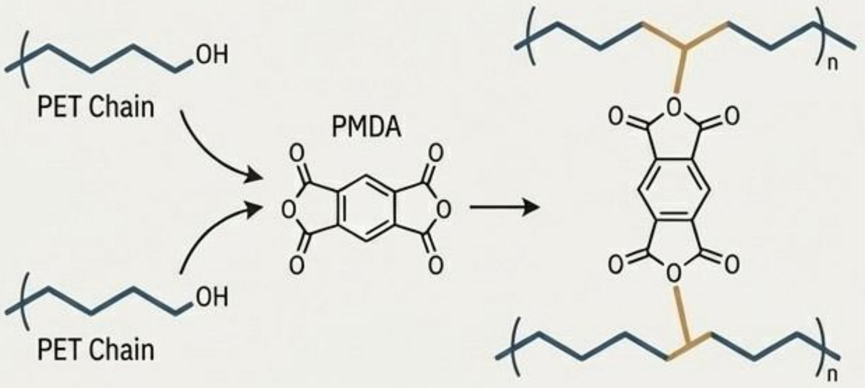
BOXIN

The Chemistry of Reconstruction: How Chain Extenders Rebuild PET

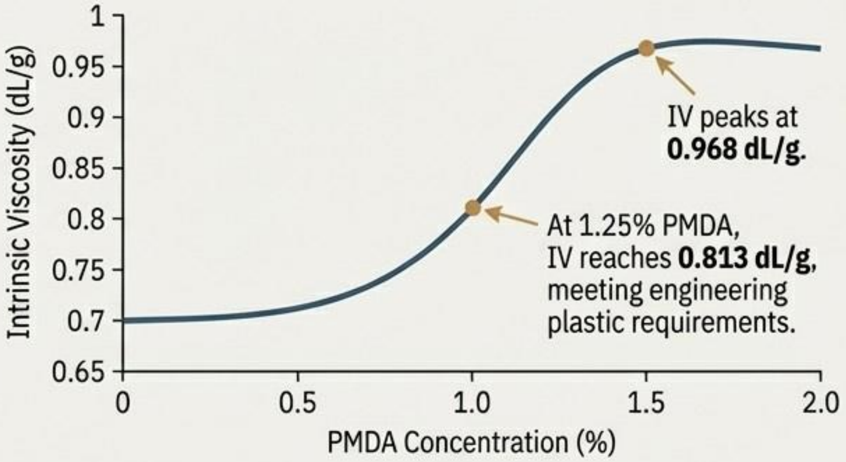
Mechanism

Chain extenders are multi-functional molecules that react with the end-groups (hydroxyl or carboxyl) of degraded PET chains. By forming new covalent bonds, a single chain extender molecule can link two or more PET chains, rapidly increasing the overall molecular weight and IV.

Case Study: PMDA - Pyromellitic Dianhydride



IV Lift vs. PMDA Concentration



This demonstrates a direct, controllable relationship between chain extender concentration and the final properties of the upgraded rPET.

BOXIN

Strategic Decision Matrix: Comparing SSP and LSP/Reactive Routes

Parameter	Solid-State Polycondensation (SSP)	Liquid-State Polycondensation (LSP) / Reactive
Reaction Temperature	210 - 230°C (Below M.P.)	275 - 295°C (Above M.P.)
Typical IV Lift	0.75 → **0.85 - 1.0 dL/g**	0.75 → **1.0 - 1.3+ dL/g**
Reaction Time	8 - 16 hours	0.5 - 4 hours
Capital Investment	Medium	High
Energy Consumption	Lower (~0.3-0.5 kWh/kg)	Higher
Final Product Quality	**Excellent Purity**: Acetaldehyde < 1ppm. Ideal for food contact.	**High Performance**: Can have slightly deeper color (yellowness) due to higher processing temperatures.
Primary Application	High-volume, continuous production (e.g., Bottle-to-Bottle)	High-performance, specialty applications (e.g., Tire Cord, Polymer Alloys)

BOXIN

Matching the Technology to the Market Need

Titler: Bottle-to-Bottle Recycling
Required IV: 0.80 - 0.85 dL/g
Critical Requirement: Acetaldehyde (AA) content < 1 ppm.
Recommended Technology: Solid-State Polycondensation (SSP). It reliably meets IV targets and excels at removing AA, making it the ideal choice for food-contact applications.

Application: Industrial Fibers & Strapping
Required IV: 0.90 - 1.0 dL/g
Critical Requirement: High tensile strength and consistency.
Recommended Technology: High-Intensity SSP or mild Liquid-State Polycondensation (LSP). Both can achieve the necessary molecular weight for these demanding applications.

Application: High-Tenacity Tire Cord & Engineering Composites
Required IV: > 1.2 dL/g
Critical Requirement: Maximum possible molecular weight for extreme strength and durability.
Recommended Technology: Liquid-State Polycondensation (LSP). Essential for reaching the ultra-high IV levels required.

Application: Small-Batch Specialty Alloys & Compounds
Required IV: Variable (recipe-dependent)
Critical Requirement: Flexibility to modify formulas and compound materials.
Recommended Technology: Reactive Extrusion. Unmatched versatility for product development and customized material production.