Introduction to Polyolefins

Polyethylene and Polypropylene
2010

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  - Classification
  - Global production

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  - Domestic production and consumption
  - Investment and operating costs of polyolefins plants
### Synthetic Polymers Classification by Plastics Europe

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Plastics</td>
<td>PE, PP, PVC, PS, EPS, PET (Bottle grade)</td>
</tr>
<tr>
<td>Engineering Plastics</td>
<td>ABS, SAN, PA, PC, PBT, POM, PMMA, Other High Performance Polymers</td>
</tr>
<tr>
<td>PUR</td>
<td>Polyurethanes</td>
</tr>
<tr>
<td>Thermoplastics</td>
<td>Standard Plastics + Engineering Plastics</td>
</tr>
<tr>
<td>Plastic Materials</td>
<td>Standard Plastics + Engineering Plastics + PUR</td>
</tr>
<tr>
<td>Plastics</td>
<td>Plastic Materials + Others (Thermosets, Adhesives, Coatings, Sealants)</td>
</tr>
<tr>
<td>Elastomers</td>
<td>Synthetic Elastomers (SBR, IR, IIR, BR, NBR, CR, Others)</td>
</tr>
<tr>
<td>Fibres</td>
<td>PA, Polyester, Acrylic, Other Synthetic Fibres</td>
</tr>
<tr>
<td>Synthetic Polymers</td>
<td>Plastic Materials + Fibres + Elastomers + Others (Thermosets, Adhesives, Coatings, Sealants)</td>
</tr>
</tbody>
</table>
World Synthetic Polymers Production 2007

- Synthetic Polymers production in 2007 approximately 315 million t globally

- PE+PP represents 114 million t or 36% of global Synthetic Polymers production
World Plastics Production
1950 - 2008

Includes Thermoplastics, Polyurethanes, Thermosets, Elastomers, Adhesives, Coatings and Sealants and PP-Fibres. Not included PET-, PA- and Polyacryl -Fibres
Source: PlasticsEurope
Polyolefins

PE and PP
The Polyolefins Family

- Polyethylene - PE
  - LDPE
  - HDPE/MDPE
  - LLDPE
- Polypropylene - PP
  - Homopolymers
  - Random copolymers
  - Impact copolymers (heterophaslic copolymers, block copolymers)
PE Classification by Density

<table>
<thead>
<tr>
<th>DENSITY</th>
<th>COMONOMER</th>
<th>PE GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.926-0.970</td>
<td>-/alfa-Olefins</td>
<td>HDPE</td>
</tr>
<tr>
<td>0.926-0.940</td>
<td>alfa-Olefins</td>
<td>MDPE</td>
</tr>
<tr>
<td>0.915-0.935</td>
<td>-/Acrylates/VA</td>
<td>LDPE</td>
</tr>
<tr>
<td>0.915-0.926</td>
<td>alfa-Olefins</td>
<td>LLDPE</td>
</tr>
</tbody>
</table>

Schematic representation of various PE structures

- **HDPE**
- **MDPE**
- **LLDPE**
- **LDPE**
PP Structures

- **Isotactic homopolymer**
- **Atactic homopolymer**
- ** Syndiotactic homopolymer**

**Block copolymer, Heterophasic copolymer - HECO**

```
PPPPPEEEEEPPPPPPPPPEEEEPPPPP
```

**Random copolymer - RACO**

```
PPPPPEPPEPEPPPPPPPEPPEPPPPP
```


Key Properties

- Molecular weight
- Molecular weight distribution
- Melt index
- Density
- Mechanical
- ESCR
Molecular weight

- Number average

\[ M_n = \frac{\sum N_i M_i}{\sum N_i} = \frac{\sum w_i}{\sum w_i / M_i} \]

- Weight average

\[ M_w = \frac{\sum N_i M_i^2}{\sum N_i M_i} = \frac{\sum w_i M_i}{\sum w_i} \]

- Polydispersity – measure of molecular weight distribution

\[ P = M_w / M_n \]
Molecular weight distribution

- Number average molecular weight ($M_n$)
- Weight average molecular weight ($M_w$)

Number of molecules

Molecular weight
Bimodal Polymer
Molecular structure vs. properties
Melt Index

- Melt index - measure of ease of flow
  - One kind of viscosity
  - Instead of determination of molecular weight
  - Fast standard method to
    - control quality
    - compare products

- Melt index and molecular weight
  - High melt index=low viscosity=low molecular weight
  - Low melt index=high viscosity=high molecular weight

- Non Newtonian behaviour
  - Melt index (viscosity) depends on load
  - Melt indices measured at different loads give indication on molecular weight distribution
Density (D)

- Depends on comonomer content (SCB=short chain branching): more SCB = lower D
- Longer comonomer chain = lower D
- Comonomers tend to incorporate into lower $M_w$ molecules deteriorating organoleptic properties
- Strong influence on important PE properties

![Diagram showing Crystalline layers and Tie molecules with labels: Crystalline layers: Stiffness, Tie Molecules: ESCR, Impact Strength]
Mechanical Properties 1

- Tensile strength (TS)
  - Higher crystallinity results in higher TS
  - \( TS_{PP} > TS_{HDPE} > TS_{LDPE} \)
  - TS measured on both machine (MD) and transversal direction (TD) on film
Mechanical Properties 2

- Impact strength (IS)
  - Ability to withstand shock loading
  - Higher $M_w$ = higher IS
  - Lower D = higher IS
  - Dart drop: special impact test for film grades
Mechanical Properties 2

- Flexural modulus (FM)
  - Measure of stiffness – higher FM means higher stiffness
  - Higher D = higher FM
  - FM_{PPHOMO} > FM_{PPHECO} > FM_{PPRACO}
ESCR - Environmental Stress Cracking Resistance

- Ability to withstand cracking under load in chemicals
- Mainly used for PE - very important for blow moulding and pipe grades
- Lower $D$ = higher ESCR
- Higher $M_W = higher ESCR$
- Role of comonomer distribution – comonomers built into high $M_W$ molecules give very good ESCR
Polyolefins mainly PP and HDPE need different additives to meet end use requirements. Typical concentration: some hundreds through some thousands ppm (1 ppm = 1 g/t).

Typical polyolefins additives:
- **Stabilizers** - to protect polymer from oxidative degradation during:
  - Processing – melt stabilization (high temperature, short time + oxygen)
  - Long term use
    - thermal stabilization (low temperature, long time + oxygen)
    - UV stabilization – ( low temperature, long time, UV light + oxygen)

**Processing aids and property modifiers**
- Slip agents – to reduce friction during processing
- Antistatic agent – to prevent build up of electrostatic charging
- Antiblocking agent – to avoid sticking of film layers
- Nucleating agents – to improve stiffness
- Clarifying agents – to increase product transparency
Global Consumption

Million T/a

Domestic Production and Consumption

![Bar chart showing PE production and consumption, PP production, and PP consumption from 2001 to 2009. The x-axis represents years from 2001 to 2009, and the y-axis represents KT/a. The chart includes data points for production and consumption for each year.]
Development of Plant Capacities

Typical single line plant capacity
Evolution of Extruder Capacities

- Polypropylene
- Polyethylene

kt/year

t/hr
Investment Costs

- Basis: USGC 2008Q1; 400 kt/year capacity
- Total investment costs of polyolefin plants without licence fee
  300-400 million USD
- Cost breakdown

Source: Nexant
Operating Costs

- Basis: USGC 2008Q1; 400 kt/year plant
- Typical operating cash cost of polyolefin plants: 1430-1530 USD/t
- Cost breakdown

Source: Nexant
Appendix

Typical investment cost elements

- **ISBL – Inside battery limit**
  - From raw material feed through pelletizing (civil work, foundations, equipment, piping, instrumentation, electricals, control room, MCC, painting and insulation, construction, supervision, etc.)

- **OSBL – Outside battery limit**
  - Pellet blending, storage and packaging
  - Utilities (e.g. power supply, steam boiler, cooling water system), flare, feedstock storage, pollution control, buildings, spare parts, etc.

- **Other project costs**
  - Start-up (Services, training programs, operating manuals, modifications and maintenance during start-up, etc.)
  - Miscellaneous owner’s costs (e.g. long distance pipeline, insurance, various studies, travel and living, engineering, transport of equipment, etc.)
  - Working capital