VRLA Battery Separator: Polymer Production

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Current Technology: AGM separator

Project Objective: Replace AGM with polymer separator
- Forecasted 2012 Production Volume: 1.75 MM m² separator mat
- Chosen Polymer System:
  0.6 wt % maleated polypropylene (PP-MAH)

Two Processes Considered Simultaneously
- PP Plant (20,000 kg/hr)
- MAH Grafting of PP (34 kg/hr)

Recommendation:
Buy PP-MAH pellets from an outside supplier
SPHERIPOL POLYPROPYLENE PRODUCTION

- Specific PP production: 400 kg/hr-m³
- Prepolymerization (R-100)
  - 20 °C, 4 MPa, 0.5 m³
- Bulk polymerization (R-101)
  - 70 °C, 4 MPa, 49.5 m³
- L/D_i = 160
- Recycle ratio = 30
  - Re = 6.2×10⁶
- Low-alloy steel

\[ V = 0.25\pi D_i^2 L \]
\[ Q = \dot{m}\Delta H_{rxn} = UA\Delta T_m \]
\[ A = 0.80\pi L(D_i + 2t_s) \]
\[ U = 1.745 \text{ kJ} / m^2 \cdot K \cdot s \]
POLYPROPYLENE PURIFICATION

- Heater (E-100)
- Flash (V-100)
- Adjunct Heater (E-101)
- Cooler (E-102)
- Pneumatic Conveyor (LPS)
- Direct-Heat Rotary Dryer (E-7)

For $3<L/D<5$:

\[
(u_V)_{\text{max}} = K_V \sqrt{\frac{\rho_l - \rho_v}{\rho_v}}
\]

\[
A_{\text{cross, min}} = \frac{Q_v}{(u_V)_{\text{max}}}
\]

Maleation of Polypropylene

- Three Segments
  - Melting/Preheating
  - First DBHA injection (0.001 M)
  - Second DBHA injection (0.001 M)

\[
\frac{-d[M]}{dt} = \frac{k_g}{1 + f} \sqrt{\frac{2k_d (1 + k_d t) e^{-k_d t} [I_0]}{k_t} \frac{[M]_0}{[M]}}
\]

- Each segment 0.6 m in length
- L/D = 42
- Extruder operates at 180 °C
- Overall MAH conversion: 13%
- 10 kW heating provided by electricity
SEPARATIONS

- Devolatizer
  - Modeled products as tert-Butanol and MAH only
  - Operate at 190 °C

- Distillation Case
  - Vacuum pump (P-200)
  - Cooler (E-200) – condense vapor
  - Pump (P-201) – raise pressure to 101 kPa
  - Column (T-200) – separate tert-Butanol and MAH
  - MAH is recycled to extruder

- Alternative Separation Schemes
  - Flash separation
  - Strictly waste disposal
SAFETY & ENVIRONMENTAL CONSIDERATIONS

Process Hazards
- Exothermic polymerization
- High pressures (BLEVE & VCE)
- High temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>Health</th>
<th>Flammability</th>
<th>Reactivity</th>
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</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>1</td>
<td>4</td>
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<tr>
<td>Hydrogen</td>
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<td>4</td>
<td>0</td>
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<tr>
<td>MAH</td>
<td>3</td>
<td>1</td>
<td>1</td>
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<tr>
<td>DBHA</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>tert-Butanol</td>
<td>1</td>
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</table>
ECONOMIC ANALYSIS OF SPHERIPOL PROCESS

- **PP Production**
  - $C_{TCI}$: $41$ MM
    - Working Capital: 73%
  - Annual Sales: $276$ MM

- **Annual Production Cost:** $245$ MM
  - 3.5 operators per shift
  - Feedstocks: 83%

- **Annual Royalties:** $8.3$ MM
- **IRR:** 93%
- **Payback Period:** ~0.5 years

### Capital Costs
- Loop Reactors
- Flash Drum
- Working Capital
- Royalties
- Other

### Annual Costs
- Feedstocks
- Utilities
- Operations
- Annual Royalties
- Other
**Economic Analysis of Grafting**

- **Grafting**
  - $C_{TCI}$: $1.01$ MM
    - No storage
    - Extruders: 48%
  - Annual Sales: $1.40$ MM

- **Annual Production Cost:** $1.27$ MM
  - 0.5 operators per shift
  - Operations: 20%

- **IRR:** 30%
- **Payback Period:** ~6 years
**Economic Analysis of Grafting**

- **PP-MAH purchase**
  - $C_{TCI}$: $0.353$ MM
    - Storage Tank: 37%
    - Working Capital: 49%
  - Annual Sales: $1.40$ MM

- **Annual Production Cost**: $1.15$ MM
  - 0.5 operators per shift
  - Feedstock costs comparable

- **IRR**: 80%

- **Payback Period**: ~2 years
PRICE SENSITIVITY

IRR as a function of...

- PP-MAH Purchase Price

**PP production profitability is too sensitive to price fluctuations.**

- PP Selling Price
- Polypropylene Price
- Propylene Purchase Price

PP-MAH profitability can withstand price changes.
## SUMMARY & RECOMMENDATIONS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>( C_\text{TCl} ) ($MM)</th>
<th>Annual Production Cost ($MM/yr)</th>
<th>( \text{Maximum Net Earnings} ) ($MM/yr)</th>
<th>IRR (%/yr)</th>
<th>Approximate Payback Period (yr)</th>
<th>Risk</th>
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<tbody>
<tr>
<td>Spheripol + Grafting</td>
<td>41.7</td>
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<td>PP-MAH Purchase</td>
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<td>0.164</td>
<td>80</td>
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</table>

### Option 1
- Manufacture PP
- Graft with MAH

### Option 2
- Purchase PP from Distributor
- Graft with MAH

### Option 3
- Purchase PP-MAH from Distributor
QUESTIONS

- Thank you to Exide Technologies for sponsoring this project.