Formacel®1100 (FEA-1100), a Zero ODP and Low GWP Foam Expansion Agent for the Appliance Industry

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2013 Polyurethanes Technical Conference
Phoenix Arizona
September 23-25, 2013
Outline

• Introduction
• Properties of Formacel® 1100
• Experimental Work
• Appliance Trial Results
• Summary
Challenges for the Appliance Industry

More stringent environmental & energy requirements

<table>
<thead>
<tr>
<th></th>
<th>HCFCs (HCFC-141b)</th>
<th>HFCs (HFC-245fa)</th>
<th>HCs (Hydrocarbons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODP</td>
<td>Low</td>
<td>Zero</td>
<td>Zero</td>
</tr>
<tr>
<td>GWP</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>VOC</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>k-factor</td>
<td>Low</td>
<td>Higher</td>
<td>Much higher</td>
</tr>
</tbody>
</table>

Challenges - meet the requirements of environmental sustainability and energy efficiency while maintaining the cost effectiveness
Formacel® 1100 – a Sustainable & Balanced Option with Unique Properties

- A zero ODP and low GWP version of HCFC-141b
- The only zero ODP option that also provides low GWP, non-VOC, low toxicity, non-flammability, low thermal conductivity and suitable boiling point
- Excellent option to blend with commercially available FEAs for performance improvement

<table>
<thead>
<tr>
<th>Property</th>
<th>Formacel® 1100</th>
<th>HCFC-141b</th>
<th>HFC-245fa</th>
<th>HFC-365mfc</th>
<th>Cyclopentane</th>
<th>Methyl Formate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecule Structure</td>
<td>CF3CH=CHCF3</td>
<td>CCl2FCH3</td>
<td>CF3CH2CHF2</td>
<td>CF3CH2CF2CH3</td>
<td>(CH2)5</td>
<td>CH3(HCOO)</td>
</tr>
<tr>
<td>ODP</td>
<td>0</td>
<td>0.11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GWP(100yr ITH)</td>
<td>8.9</td>
<td>725</td>
<td>1030</td>
<td>794</td>
<td>11</td>
<td>&lt;25</td>
</tr>
<tr>
<td>VOC</td>
<td>No[1]</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Exposure Limits (ppm)</td>
<td>500[2]</td>
<td>500</td>
<td>300</td>
<td>1000</td>
<td>600</td>
<td>100</td>
</tr>
<tr>
<td>Flammability</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lambda @ 25 C (mW/mK)</td>
<td>10.7</td>
<td>9.7</td>
<td>12.7</td>
<td>10.5</td>
<td>13</td>
<td>10.7</td>
</tr>
<tr>
<td>Boiling Point (C)</td>
<td>33</td>
<td>32</td>
<td>15</td>
<td>40</td>
<td>49</td>
<td>32</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>164</td>
<td>117</td>
<td>134</td>
<td>148</td>
<td>70.1</td>
<td>60</td>
</tr>
</tbody>
</table>

[1] Expected based on low MIR number
[2] AEL is DuPont Acceptable Exposure Limits (8-12 hr TWA)
Experimental Work

• Bench scale experiments by DuPont [1, 2]
  - Formacel® 1100 blends improved k-factor
  - Formacel® 1100 at reduced level provided equivalent or improved k-factor performance

• High pressure machine experiments by Dow Chemical [3]
  - Formacel® 1100 was dropped into an appliance formulation using cyclo-/iso-pentane (Cpisp) blend
  - The molar ratio of Formacel® 1100 was varied from 100% to 0% as designated as FEA100, FEA80, FEA60, FEA50, FEA40, FEA20 and FEA zero (100% Cpisp)
  - Several performance advantages were identified

Reactivity Profile

- Similar reactivity profile at various Formacel® 1100 levels
- Potential drop-in replacement with minimum reformulation efforts
Foam Flow and Density

- Better flow and lower density
- Potential opportunity to use less foam material per refrigerator unit
Demold Expansion

- Similar or slightly less demold expansion
- No negative impact on productivity
- Potential demold time reduction
Compressive Strength

- Comparable compressive strength even with lower density
- Potential density reduction without negative impact on compressive strength
Creep Deformation

- Comparable creep deformation even with reduced density
- Potential density reduction without negative impact on dimensional stability
• Reduced k-factor at various Formacel® 1100 levels
• Potential k-factor improvement with reduced Formacel® 1100 usage
Summary of Performance Advantages

• Similar reactivity profile
  ➢ Drop-in to the existing HC formulation with minimum reformulation work
  ➢ Use of existing HC production process without modification

• Improved flow
  ➢ Foam cost reduction (less foam material per refrigerator unit)
  ➢ Similar demold performance
  ➢ Potential opportunity for demold time reduction

• k-factor improvement
  ➢ Improve energy efficiency
  ➢ Reduce Formacel® 1100 usage to balance cost and energy efficiency
Appliance Trial

- Full-scale appliance trial in a Whirlpool production facility
  - The zero ODP and low GWP foam expansion agent, Formacel® 1100 was supplied by DuPont
  - Foam systems using Formacel® 1100 and Formacel® 1100-HC blend were developed by Dow Chemical
  - Tooling and cabinets/doors were supplied by Whirlpool

- Trial details
  - Formacel® 1100 was dropped into a commercial HC formulation without optimization
  - The existing production process/equipment was used without modification/optimization
  - Refrigerators were built using Formacel® 1100 & Formacel® 1100-HC blend
  - Ratio of Formacel® 1100 in blend was determined based on economic factors of FEAs
Performance Evaluation vs HC Control

• Cabinet and door foam processing
  ➢ Drop-in performance
  ➢ Foam shot weight
  ➢ Demold performance

• Foam properties
  ➢ Core density
  ➢ Compressive strength
  ➢ Dimensional stability and creep deformation
  ➢ Liner compatibility
  ➢ K-factor and aged k-factor

• Energy consumption
Cabinet & Door Foam Processing

- Same equipment/process conditions
- No process or productivity issue
- Improved foam flow
- Reduced 4 - 6% foam shot weight (improved foam cost effectiveness)

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>Formacel® 1100 -HC blend</th>
<th>Formacel® 1100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total output rate (g/sec)</td>
<td>1255</td>
<td>1255</td>
<td>1255</td>
</tr>
<tr>
<td>Injection pressure (kg/cm²)</td>
<td>140 - 150</td>
<td>140 - 150</td>
<td>140 - 150</td>
</tr>
<tr>
<td>Mold/fixture temperature (ºC)</td>
<td>40 - 50</td>
<td>40 - 50</td>
<td>40 - 50</td>
</tr>
<tr>
<td>Chemical material temperature (ºC)</td>
<td>20 - 23</td>
<td>20 - 23</td>
<td>20 - 23</td>
</tr>
<tr>
<td>Demold time</td>
<td>Control</td>
<td>Identical</td>
<td>Identical</td>
</tr>
<tr>
<td>Gel time</td>
<td>Control</td>
<td>Within 10%</td>
<td>Within 10%</td>
</tr>
<tr>
<td>Foam flow</td>
<td>Control</td>
<td>Better</td>
<td>Much better</td>
</tr>
<tr>
<td>Foam shot weight</td>
<td>Control</td>
<td>-4%</td>
<td>-6%</td>
</tr>
</tbody>
</table>
Foam Core Density

- Lower foam density with the addition of Formacel® 1100
- Less foam material per refrigerator unit

![Average Foam Core Density Comparison](chart.png)
Compressive Strength

- Comparable compressive strength with lower density
- Less foam usage without negative impact on foam mechanical property
Dimensional Stability & Creep Deformation

- Comparable dimensional stability after 1 year storage at -25 °C
- Creep deformation within specifications with lower density
- Less foam usage without negative impact on foam dimensional stability
Liner Compatibility

- High impact polystyrene (HIPS) used in the refrigerator model
- Thermal cycle test
  - Refrigerators were heated to 50°C for 10 hours then cooled to -23°C for an additional 10 hours
  - The cycle was repeated for 8 days
- Comparable performance for refrigerators using Formacel 1100® & Formacel 1100®-HC blend
  - No visual defects such as blistering or cracking
  - Comparable to HC baseline
**Average k-factor & Aged k-factor**

- **Sampling:** Core foams from different locations in cabinets and doors
- **Average k-factor:** 5-10% reduction compared to HC control
- **Aged k-factor:** Improvement maintained after 5 months of aging

![Relative k-factor vs HC Control](image-url)
Energy Consumption

Energy efficiency improvement: 4 - 10% reduction in energy consumption

Energy Consumption Comparison

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>Formace® 1100-HC blend</th>
<th>Formace® 1100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Consumption</td>
<td>1.0</td>
<td>0.96</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Impact of Formacel® 1100 Concentration in Foam Cell – k-factor

- Refrigerators with higher level of Formacel® 1100 in foam cells were also evaluated
- Formacel®1100-HC blend with higher Formacel®1100 concentration showed lowest k-factor at 10°C
- All other standard foam properties met specifications
Impact of Formacel® 1100 Concentration in Foam Cell – Energy Consumption

- Formacel®1100-HC blend with higher Formacel®1100 concentration showed lowest energy consumption
- Formacel®1100 level can be optimized to balance energy efficiency and cost effectiveness
Summary

• DuPont has developed Formacel® 1100, a zero ODP and low GWP foam expansion agent for the appliance industry
• Dow Chemical developed Formacel® 1100 foam systems with significant performance benefits
• Whirlpool confirmed the performance benefits in a full-scale production trial
• Formacel® 1100 can be dropped into a HC production line without process/equipment modification
• The demold performance is comparable to the HC system, with potential for demold time reduction
• The foam cost effectiveness per refrigerator unit can be improved without any negative impact on foam properties
• The energy efficiency of the refrigerators can be significantly improved
• Formacel® 1100 level can be optimized to balance energy efficiency and cost effectiveness
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