2015 Japan Technology Summit
Yokohama, September 9-10

Honeywell Blowing Agent for LNG Insulation
Katsuyuki Matsui, Fluorine Products, Honeywell
Agenda

• Who is Honeywell

• Blowing agent and polyurethane foam basics

• Industry / Regulatory drivers

• Applications of Enovate 245fa in LNG industry
  – LNG carrier
  – LNG onshore Tank
  – LNG piping insulation

• Introduction of Solstice LBA

• Conclusion
Honeywell

- $40.3B in sales for 2014
- 55% sales outside U.S.
- ~1,250 sites, 70 countries
- 127,000 employees
- Morris Plains, NJ headquarters
- Fortune 100
- 50% of portfolio focused on energy efficiency improvement

Aerospace

Performance Materials and Technologies

Automation and Control Solutions

$40.3B global company focused on energy efficiency solutions
Value Chain: Role of Honeywell

Honeywell is a supplier of ingredient used in foam insulation for LNG Carriers
Video: What is Blowing Agent

Play the prepared video
Polyurethane Foam Basics

• Foam created by trapping gas in a polymer matrix
  – The gas is the “Blowing Agent” (BA)

• BA has several functions in the foam
  – Expands the foam
  – Supports cell structure
  – Provides insulation

Two Main Types of BAs

<table>
<thead>
<tr>
<th>Physical</th>
<th>Chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enovate® 245fa</td>
<td>Water (CO₂)</td>
</tr>
<tr>
<td>Solstice ® LBA</td>
<td></td>
</tr>
<tr>
<td>365mfc</td>
<td></td>
</tr>
<tr>
<td>HCFC-141b</td>
<td></td>
</tr>
</tbody>
</table>

Type of gas in the cell has large influence on foam properties

Source: Internal Honeywell lab data based on 2-lb foam
Blowing Agent Basics

• BA delivers up to 70% of a foam’s insulating value
  – Choice of BA influences how much LNG could be saved through lower "boil-off rate" (BOR) over the life of a LNG Carrier

• Not all BAs are equal
  – Some are better insulators (lambda) which leads to better BOR
  – Some have better environmental properties than others—
    ♦ Global Warming Potential (GWP)
    ♦ Ozone Depleting Potential (ODP)
    ♦ Volatile Organic Compound (VOC)
  – Some are safer to use than others
    ♦ Flammability
  – Some make foam with higher strength and able to withstand external conditions over time

Choice of blowing agent critical to insulation/mechanical performance
Fluorine Products Generations of New Products

1930s – 1990s
- CFCs (Chlorofluorocarbons)
  - Ozone Depleting: Yes
  - ODP: 1.0
  - Global Warming: Yes
  - GWP: 8000
- Honeywell Products: Genetron®

1990s
- HCFCs (Hydrochlorofluorocarbons)
  - Ozone Depleting: Yes
  - ODP: 0.1
  - Global Warming: Yes
  - GWP: 2000
- Honeywell Products: Genetron® Enovate®

2000s
- HFCs (Hydrofluorocarbons)
  - Ozone Depleting: No
  - ODP: 0
  - Global Warming: Yes
  - GWP: 1000
- Honeywell Products: Solstice®

2010s
- HFOs (Hydrofluoroolefins)
  - Ozone Depleting: No
  - ODP: 0
  - Global Warming: Yes
  - GWP: ≤ 1
- Honeywell Products: Genetron®

Honeywell innovation to achieve environmental breakthroughs
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Honeywell Enovate® 245fa Blowing Agent
# Commercial Blowing Agents Comparison

<table>
<thead>
<tr>
<th>Performance at Cryogenic Temperature</th>
<th>141b</th>
<th>365mfc</th>
<th>Enovate® 245fa</th>
<th>Solstice® LBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td><img src="image1" alt="141b" /></td>
<td><img src="image2" alt="365mfc" /></td>
<td><img src="image3" alt="Enovate® 245fa" /></td>
<td><img src="image4" alt="Solstice® LBA" /></td>
</tr>
<tr>
<td>Ozone Depletion Impact</td>
<td><img src="image1" alt="141b" /></td>
<td><img src="image2" alt="365mfc" /></td>
<td><img src="image3" alt="Enovate® 245fa" /></td>
<td><img src="image4" alt="Solstice® LBA" /></td>
</tr>
<tr>
<td>Low Global Warming Potential</td>
<td><img src="image1" alt="141b" /></td>
<td><img src="image2" alt="365mfc" /></td>
<td><img src="image3" alt="Enovate® 245fa" /></td>
<td><img src="image4" alt="Solstice® LBA" /></td>
</tr>
<tr>
<td>Flammability</td>
<td><img src="image1" alt="141b" /></td>
<td><img src="image2" alt="365mfc" /></td>
<td><img src="image3" alt="Enovate® 245fa" /></td>
<td><img src="image4" alt="Solstice® LBA" /></td>
</tr>
</tbody>
</table>

- Phased-out in US, EU, Canada, Japan, etc.
- Phasing out in other countries

*Enovate & Solstice offers best balance of performance and environment attributes*
Applications of Enovate® 245fa in LNG Industry

Enovate 245fa is currently used in onshore and offshore LNG applications
In 2014, >50% of LNG ships were adopted and built with Enovate 245fa and the adoption is accelerating.
Trend of Insulation in LNG Carrier

- Lower and lower BOR is desired in the LNG carrier industry
- Enovate 245fa provides superior insulation performance at cryogenic temperature
  
  Better Insulation Performance at cryogenic temperature
  - Lower BOR
  - Reduced LNG Loss during transport
  - Increase LNG Delivery
  - Maximize Profit

- Enovate® 245fa option is now available in the following LNG carrier types
  - Mark III & Mark III Flex
  - NO96-LO3
  - Moss-type

BOR with Enovate 245fa can be as low as 0.09%/day
Insulation Performance of Various Blowing Agents

**4 Months Aging Thermal Conductivity**

Thermal Conductivity, mW/mK

15% Better Insulation Power at -160 °C

Lower = Better Insulation

*Enovate® 245fa offers the best insulation value*
Insulation Performance and BOR Performance

**Superior thermal insulation of Enovate 245fa leads to better BOR performance**

**4 Months Aging Thermal Conductivity**

- **245fa 15% Better Insulation at -160° C**

**BOR Comparison GTT Mark III**
- Shipbuilders: Hyundai & Samsung
- Enovate® 245fa
  - 5% - 6% Better
- Carbon Dioxide
  - 5% - 6% Worse

**BOR Comparison GTT NO96-LO3**
- Shipbuilders: DSME
- Glasswool + Enovate 245fa foam
  - 38% Better
### GTT Mark III Flex Type

<table>
<thead>
<tr>
<th>Containment Insulation Material</th>
<th>BOR, %/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU Foam with Water (CO₂)</td>
<td>0.10%</td>
</tr>
<tr>
<td>PU Foam with HCFC-141b</td>
<td>0.095%</td>
</tr>
<tr>
<td>PU Foam with Enovate® 245fa</td>
<td>0.09%</td>
</tr>
</tbody>
</table>

### GTT NO96 Type

<table>
<thead>
<tr>
<th>Containment Insulation Material</th>
<th>BOR, %/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perlite</td>
<td>0.15%</td>
</tr>
<tr>
<td>Glass Wool</td>
<td>0.128%</td>
</tr>
<tr>
<td>Glass Wool + PU Foam w/ Enovate 245fa</td>
<td>0.108%</td>
</tr>
</tbody>
</table>

**Enovate 245fa provides the lowest BOR for both Mark III and NO96 ships**
Enovate® 245fa in LNG Onshore Storage Tanks

Enovate 245fa is now being used in membrane type and full containment design tanks.
Trend of Insulation in LNG Onshore Tanks

- Low BOR is desired for LNG onshore tanks
- Safety is always a concern for LNG onshore tanks
- Suitable Applications: LNG tank located in:
  - Factory or manufacturing plant
  - LNG refuel station for vehicles or vessels
  - Remote area which is hard to access by road
- Enovate® 245fa option is now available in the following LNG tank types
  - Full containment design tank
  - GTT membrane type design tank: GST

Enovate 245fa provides thermal efficiency and protection for LNG tanks
Performance of Enovate® 245fa in LNG Tank

Benefits

- Efficient thermal protection for the concrete outer tank
- Efficient corner protection for the inner steel tank
- Enhanced cryogenic temperature insulation performance
- Potentially reduced land space requirement

Enovate 245fa provides the best cryogenic insulation performance
Enovate® 245fa in LNG Pipe Insulation

In 2015, DUNA-USA reports 12% better insulation performance by adopting Enovate 245fa
Performance of Enovate® 245fa in Pipe Insulation

**Benefits**
- Better Insulation Performance
- Improved Processability
- Greater Mold Flow
- Better Flame Spread Index

**Enovate 245fa improves piping insulation**
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The New Generation
Honeywell Low Global Warming Potential Blowing Agent Platform
## Low Global Warming Options from Honeywell

### Applications

<table>
<thead>
<tr>
<th></th>
<th>Honeywell Low Global Warming Offerings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foams</td>
<td>Solstice® GBA</td>
</tr>
<tr>
<td></td>
<td>Solstice LBA</td>
</tr>
<tr>
<td>Refrigerants</td>
<td>Solstice yf</td>
</tr>
<tr>
<td>Solvents</td>
<td>Solstice Performance Fluid</td>
</tr>
<tr>
<td>Aerosols</td>
<td>Solstice Propellant</td>
</tr>
</tbody>
</table>

**Low GWP solutions for foam, refrigerant, solvent and aerosols**
### Environmental Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Solstice LBA</th>
<th>245fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Life</td>
<td>26 days**</td>
<td>7.6 years</td>
</tr>
<tr>
<td>ODP</td>
<td>~ 0*</td>
<td>~ 0*</td>
</tr>
<tr>
<td>GWP&lt;sub&gt;100&lt;/sub&gt;</td>
<td>1 **</td>
<td>825</td>
</tr>
<tr>
<td>VOC</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

### Safety Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Solstice LBA</th>
<th>245fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammable****</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Exposure Limit (OEL)</td>
<td>800 ppm***</td>
<td>300 ppm</td>
</tr>
</tbody>
</table>

### Physical Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Solstice LBA</th>
<th>245fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point, °F</td>
<td>66</td>
<td>60</td>
</tr>
<tr>
<td>Molecular Weight, g/mol</td>
<td>130</td>
<td>134</td>
</tr>
</tbody>
</table>

*No impact on ozone layer depletion and is commonly referred to as zero (Wuebbles, private communication)


*** Preliminary HON OEL (occupational exposure limit)

**** As per ASTM E-681
Performance of Solstice® LBA Vs Enovate® 245fa

Initial Lambda

Aged Lambda, 28days at RT/50%R.H.

Best thermal insulation performance at all evaluated temperatures
Solstice® LBA Adoptions Accelerating Globally

Solstice is the ideal option for meeting insulation & environmental requirements
Solstice® LBA Blowing Agent

• Favorable environmental and safety properties
  • GWP = 1
  • Non-flammable

• Global Adoption in appliance, spray foam, panel foam, refrigerated containers

• LNG Industry
  • Polyurethane foam OEMs and producers have started evaluating the performance of Solstice LBA at cryogenic temperatures

• Commercialization Status
  • Solstice LBA has already commercialized in 2014
    • 1st world-class full scale production facility in Louisiana, USA
  • Planning underway for additional plants
Honeywell Blowing Agents for LNG

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Thank you