Introduction to Spray Polyurethane Foam (SPF)

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Spray Polyurethane Foam Alliance
Learning Objectives

– Types of polyurethane foam products used for insulation and air sealing
– Unique benefits of spray polyurethane foam
– Applications within the building envelope
– Compliance with ICC model building codes
– Site safety requirements during application of SPF
History of SPF in Buildings

- Building Envelope and Roofing
  - Late 60’s - Roofing
  - Early 70’s - Medium Density Sealant
  - Mid 90’s - Low Density
SPF Chemistry

- **A-Side or MDI** (Methylene diphenyl diisocyanate)
- **B-Side or Polyol**
  - polyols
  - blowing agents
  - flame retardants
  - surfactants
  - catalysts

Proprietary blend of additives affect cell formation and foam performance
**Polyols**

Provide the hydroxyls (OH) that combine with MDI (NCO) to form polyurethane

Petroleum polyols are polyester and/or polyether blends

Some natural oil polyols, like soybean oils can be blended with petroleum polyols (20+45)
SPF Chemistry

Blowing Agents

Creates the gas needed to foam the liquid polyurethane mixture

Physical blowing agents convert from liquid to a gas from the heat of the reaction (HFC-245fa)

Reactive blowing agents are gases created from chemical reactions. Water + MDI = CO₂

Some SPF uses blend of water and HFC-245fa

Non-flammable, No VOC

Polyol, 65%

Blowing Agent, 20%

Catalysts, 3%

Surfactants, 2%

Flame Retardants, 10%

typical B-side formulation
Polyol, 65%
Flame Retardants, 10%
Blowing Agent, 20%
Catalysts, 3%
Surfactants, 2%

Flame Retardants

Polyurethane foam is an organic material and is combustible.

Without fire retardants, foam plastics could not be used in buildings

No brominated FRs – (PBDE)

Uses phosphorous-based FRs such as TCPP, TDCP and TEP

typical B-side formulation
AMINE CATALYSTS

Amine catalysts are used to control the polyurethane reaction. To achieve proper desired foam properties, competing balance between BA expansion and polyurethane curing – stabilizing the foam.

Typical B-side formulation:
- Polyol, 65%
- Blowing Agent, 20%
- Flame Retardants, 10%
- Catalysts, 3%
- Surfactants, 2%
SPF Chemistry

Typical B-side formulation:

- Polyol, 65%
- Blowing Agent, 20%
- Flame Retardants, 10%
- Catalysts, 3%
- Surfactants, 2%

Surfactants:
Surfactants control cell formation and degree of opening of panes inside each cell.
SPF Chemistry

OPEN CELL
~100x expansion
0.5 to 0.8 pcf
R-3.6 to R-4.5 per inch (air)

CLOSED CELL
~30x expansion
1.7-3.5 pcf
R-5.8 to R-6.8 per inch
(trapped HFC)
PU Foam Delivery

- 6-15 BF/min froth
- air-sealing
- Low/high expansion

One-Component (can)
PU Foam Delivery

- 30-40 BF/minute froth
- air sealing, small insulation jobs

Two-Component  (low pressure / kit)
PU Foam Delivery

- 100-500 BF/minute spray
- heated chemicals
- larger insulation and all roofing applications
- Special training and capital investment

Two-Component (high pressure)
Chemical Safety during Application

- Hazardous chemicals are used for SPF
  - A-side is reactive and can cause respiratory or dermal sensitization
  - Delivery methods affect exposure
    - Low-pressure: gloves, eyes, APR
    - High-pressure: full-skin, eyes, APR or SAR
Chemical Safety during Application

• Chemical Safety Measures
  • PPE required during and just after installation
  • Isolate, contain and vent work zone
  • SPF contractor safety plan
  • www.spraypolyurethane.com
Chemical Safety after Application

- No known chemical hazards for occupants
  - Safe MDI levels in 1-2 hours
  - 24 hour re-occupancy typical
  - Installed SPF is low-VOC (SPF is solvent-free)
    - GreenGuard Environmental Institute
    - CAN/ULC-S774 Saskatchewan Research Council
Environmental Impact

• Raw Materials
  • Petroleum vs. natural oil polyols
Reduce GWP while maintaining other desired properties

Development Progression for Fluorinated Foaming Agents

Gen 1: CFC-11 (CCl3F, ~24°C)

Gen 2: HCFC-141b (CCl2F-CH3, ~42°C)

Gen 3: HFC-245fa (CF3CH-CHF2, ~16°C)

Gen 4: HFO-1234ze (CF3CH=CHF, ~19°C)

- 1991
- 2003
- 2013
### Environmental Impact

**• Raw Materials**

- Petroleum vs. natural oil polyols
- FC blowing agent evolution

<table>
<thead>
<tr>
<th>Years</th>
<th>Generation</th>
<th>SPF Blowing Agent</th>
<th>ODP</th>
<th>GWP</th>
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</thead>
<tbody>
<tr>
<td>1960s - 1993</td>
<td>1</td>
<td>CFC-11</td>
<td>1.0</td>
<td>4750</td>
</tr>
<tr>
<td>1993 - 2003</td>
<td>2</td>
<td>HCFC-141b</td>
<td>0.12</td>
<td>760</td>
</tr>
<tr>
<td>2003 - pres</td>
<td>3</td>
<td>HFC-245fa</td>
<td>0</td>
<td>1020</td>
</tr>
<tr>
<td>2012?</td>
<td>4</td>
<td>HFO/HFE</td>
<td>0</td>
<td>6 - 15</td>
</tr>
</tbody>
</table>
Gas Diffusion Impacts Foam Aging

Region 1 - Air Infiltration & CO$_2$ Diffusion Dominate Aging

Region 2 - Both Phenomenon Impact Aging Rate

Region 3 - Blowing Agent Diffusion Dominates Aging
Environmental Impact

• Raw Materials
  • Petroleum vs. natural oil polyols
  • FC blowing agent evolution
  • Phosphate flame retardants (no brominated)
    • No brominated FRs used
    • TEP, TCPP, TDCP are typical
    • Evaluated as potential carcinogen, mutagen, reproductive system, bio-toxicity, bio-accumulative
  • Low risk per EU EEC No. 793/93 Risk Assessment
Environmental Impact

• Disposal and Recycling
  • Landfill safe
  • Mechanical grinding for fillers and packaging
  • Chemical recycling
Environmental Impact

• Life-Cycle Assessment
  • Industry-LCA in progress

  - environmental impacts prevented during use
  - environmental impacts from production

• SPF contributes to green building rating and scoring systems
  • Insulation quality, air-sealing, recycled/renewable, VOC/IAQ
SPF Performance

• Consistent Thermal Performance
• Air Impermeable
• Moisture Control
• Structural Enhancement
Thermal Performance

• Several GHB studies show 15-30% better performance

• Why?
  • Reduced internal convection
  • Reduced air infiltration
  • Consistent performance over range of operating temperatures
Thermal Performance

- Designing the Thermal Envelope with SPF

![Graph showing energy cost vs. R-value for air permeable insulation](image-url)
Thermal Performance

• Designing the Thermal Envelope with SPF

- **Spray Foam Insulation**
- **Air Permeable Insulation**

Consistent R-value and air-sealing ~ 25% savings
Thermal Performance

- Designing the Thermal Envelope with SPF

![Graph showing energy cost vs. R-value for Spray Foam Insulation and Air Permeable Insulation. The graph indicates consistent R-value and air-sealing with ~25% savings. There is a notation for better performance at the same R-value.](image-url)
Thermal Performance

• Designing the Thermal Envelope with SPF

![Graph showing the comparison between Spray Foam Insulation and Air Permeable Insulation. The graph plots Unit Cost against R-value. The yellow line represents Spray Foam Insulation, the green line represents Air Permeable Insulation. The graph highlights the following points:
- Better performance at the same R-value
- Same performance at a lower R-value, with consistent R-value and air-sealing approximately 25% savings.]
Thermal Performance

• Designing the Thermal Envelope with SPF

Adoption of a **Thermal Metric or Wall Efficiency Rating** is key
Air Barrier Performance

- **Materials**
  - Air-impermeable per ASTM E283 or E2178
  - air barrier material

- **Assemblies/Systems**
  - SPF on opaque walls + sealant foams around fenestration creates air barrier system

- ABAA Spec for MD SPF
- Integral air-barrier
Air Barrier Performance

Weatherization Case Studies  (2008 Fomo)

<table>
<thead>
<tr>
<th>Home Size (SF)</th>
<th>Minimum Ventilation (ACH\textsubscript{50})</th>
<th>Initial Air-Leakage (ACH\textsubscript{50})</th>
<th>Foam Treatment</th>
<th>Final Air-Leakage (ACH\textsubscript{50})</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>2300</td>
<td>5.4</td>
<td>9.3</td>
<td>1” Attic floor</td>
<td>7.0</td>
<td>-25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rim joist</td>
<td>6.3</td>
<td>-32%</td>
</tr>
<tr>
<td>2500</td>
<td>5.4</td>
<td>10.4</td>
<td>Rim joist</td>
<td>8.8</td>
<td>-15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100SF cantilevered floor</td>
<td>6.6</td>
<td>-37%</td>
</tr>
</tbody>
</table>
Moisture Performance

• Open-cell SPF
  • Permeability 15-40 perm-inch
  • Class III: semi-permeable at 6” or more

• Closed-cell SPF
  – Permeability 2 perm-inch
  – Class II: semi-impermeable at 2” or more
  – Special considerations for extreme cold climates, high interior humidity loads, or low interior-temperatures
Moisture Performance

- Hybrid Insulation Systems
  - MD SPF + vapor-permeable insulations to lower cost
  - Air barrier performance?
  - Vapor retarder plane
  - SPFA Guideline under development
    - IECC Zones 1-3 guideline complete
    - IECC Zone 4 and above need engineered solution
Structural Performance

- Racking strength doubled by MD SPF

Diagram showing:
- Empty Framing
- Fiberglass, Cellulose and Open-Cell SPF Insulations
- Closed-Cell SPF Insulation
Structural Performance

Houses with damaged or missing roof sheathing in Florida
Structural Performance

• Wind Uplift MD SPF (2008 Prevatt)

130-140 psf load @ 150 mph zone 3
## SPF Performance

<table>
<thead>
<tr>
<th></th>
<th>Spray Foam</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Sealant</td>
</tr>
<tr>
<td>Density (lb/ft³)</td>
<td>0.6 – 1.8</td>
</tr>
<tr>
<td>Thermal Resistivity (R/in)</td>
<td>NR</td>
</tr>
<tr>
<td>Air Impermeable Material</td>
<td>*</td>
</tr>
<tr>
<td>Integral Air Barrier System</td>
<td></td>
</tr>
<tr>
<td>Integral Vapor Retarder</td>
<td></td>
</tr>
<tr>
<td>Water Resistant</td>
<td></td>
</tr>
<tr>
<td>Cavity Insulation</td>
<td></td>
</tr>
<tr>
<td>Continuous Insulation</td>
<td></td>
</tr>
<tr>
<td>Low-Slope Roofing</td>
<td></td>
</tr>
<tr>
<td>Structural Improvement</td>
<td></td>
</tr>
</tbody>
</table>
Unvented Attics
Cathedralized Ceilings
Cathedralized Ceilings
Exosed Ductwork
Rim-Band Joists / Sill Plates
Floors (Garage Ceiling)
Floors (Cantilevered)
Below Grade Walls
Below Slab
Basement Walls
Unvented Crawlspaces
Exterior Walls
Interior Walls

LD
MD
Roof
Door and Window Sealing

Low-Expansion for windows and doors

High-Expansion for cracks and gaps
Commercial Applications

- Frame Walls
- Exterior Walls
- Low-Slope Roofs
- Metal Buildings
- Frame Walls
- Interior Walls

Other Applications
- Temporary Structures
- Tanks and Vessels
Exterior Walls
Exterior Walls
Low-Sloped Roofs
Domed Roofs
Metal Buildings

LD
MD
Roof
Temporary Structures
Tanks and Vessels
SPF and the International Codes

• Code Sections
  – Separate from ‘traditional’ insulations
  – IBC: Ch 26, Section 2603 Foam Plastic Insulation
  – IRC: Ch 3, R316 Foamed Plastic

• Code Focus
  – Fire Protection
  – Thermal Performance
  – Moisture Control
Surface Burning Test

**Surface Burning Characteristics**

[IBC 2603.3 / IRC R316.3]

- ASTM E84 / UL 723 Steiner Tunnel Test
  - Flame Spread Index (FSI)
  - Smoke Developed Index (SDI)
  - FSI/SDI is 0/0 for fiber-cement
  - FSI/SDI is 100/100 for red oak
  - Limited to 4” thickness

- Class II – FSI ≤ 75, SDI ≤ 450
- Class I – FSI ≤ 25, SDI ≤ 450
- Roofing – FSI ≤ 75, SDI unlimited
- **CHECK with manufacturer or ESR for testing >4”**
Thermal Barriers

• Thermal Barrier Requirement
  [IBC 2603.4 / IRC R316.4]
  – Separates insulation from interior of building
  – Approved 15 minute thermal barrier
    • ½” gypsum wallboard is most commonly used
    • Others to be tested per ASTM E119 and/or full-scale fire tests
  – Exceptions to Thermal Barrier requirement...
Thermal Barriers

• Special Requirements for SPF in Type I-IV Construction
  [IBC 2603.5]
  – ASTM E119 or UL 263 required for fire-resistance rated wall assemblies
  – Thermal barrier required
  – NFPA 259 test data corresponding to SPF tested per NFPA 285
  – Class I per ASTM E84 (<25 FS, <450 SD)
  – NFPA 285 test data for each wall assembly
  – Labelling of product
  – NFPA 286 test data showing no sustained flaming
Thermal Barrier Exceptions

- Inside masonry or concrete walls  
  [IBC 2603.4.1.1 / IRC R316.5.2]
- **Cooler and freezer walls***  
  [IBC 2603.4.1.2-3]
- Laminated metal wall panels-one story  
  [IBC 2603.4.1.4]
- **Roofing assembly***  
  [IBC 2603.4.1.5 / IRC R316.5.2]
- Entry doors  
  [IBC 2603.4.1.7-8 / IRC R316.5.5]
- Garage doors  
  [IBC 2603.4.1.9 / IRC R316.5.6]
- Siding backer board  
  [IBC 2603.4.1.10 / IRC R316.5.7]

* SPF applications
Thermal Barrier Exceptions

• Sill Plates and Headers  [IBC 2603.4.1.13 / IRC R316.5.11]
  – Limited to Type V construction
  – Max thickness 3.25”
  – Class I Foam (LD and MD)

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Thermal Barrier Exceptions

- **Attics and Crawl Spaces** [IBC 2603.4.1.6 / IRC R316.5.3]
  - Entry is made only for service of utilities (no storage)
  - **Ignition barrier** is required separating attic/crawlspace space from foam
  - Thermal barrier required between attic/crawlspace and occupied space

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Ignition Barrier Requirements

• Ignition Barrier  [IBC 2603.4.1.6 / IRC R316.5.3]
  – Prescriptive ignition barriers include:
    • 1.5” mineral fiber insulation
    • 0.25” wood structural panels
    • 0.375” particleboard
    • 0.25” hardboard
    • 0.375” gypsum board
    • Corrosion-resistant steel having a base metal thickness of 0.016 “
  – Alternative Assemblies by Special Approval Testing
Alternative Assemblies

• Special Approval Tests  [IBC 2603.9 / IRC R316.6]
  – **NFPA 286** - Contribution of Wall and Ceiling Interior Finish to Room Fire Growth (with the acceptance criteria of Section 803.2/R315.4)
  – **FM 4880** - Fire Rating of Insulated Wall or Wall and Roof/Ceiling Panels, Interior Finish Materials or Coatings, and Exterior Wall Systems
  – **UL 1040** - Safety Fire Test of Insulated Wall Construction
  – **UL 1715** – Fire test of interior finish material
  – *End-use fire tests*
End-Use Fire Testing

• Special Approval for Foam In Attics and Crawlspaces
  – End-use fire tests...
  • Qualifies assembly (foam alone or foam with intumescent coating)
  • See AC-377 June 2009 for updated testing requirements

New modified NFPA 286 baseline test
Thermal and Moisture

- **Thermal Performance, R-value**
  
  [IBC 1301 → IECC 102.1.1 / IRC N1102.1 / 16CFR Part 460 ]
  
  – Measure per ASTM C 518 or C 177
  
  – At installed thickness or extrapolated from R-value at representative thickness per FTC rule; Refer to ESR
  
  – Must be **aged** R-value for SPF, as applicable

- **Moisture Permeance**  [IECC 402.5 / IRC R318]
  
  – Measure per ASTM E 96 dry cup (method A)
  
  – Approximately 2 inches of closed-cell SPF provides ≤ 1 perm
SPF and Code Compliance

• ICC-ES Acceptance Criteria
  – AC-12 for Foamed Plastic: XPS, EPS, PIR
  – AC-377 for Froth and Spray Polyurethane Foams: -- NEW 3/1/08

• (A) ICC-ES Reports
  – Required Data
    • R-value, Surface Burning Characteristics (at thickness), Physical Properties
  – Optional Data
    • Air permeance, Water absorption, WVTR, Full-scale fire tests,...
  – Go to www.icc-es.org for full list of ESRs for SPF

• (B) Alternate Product Documentation
  – Code-compliance research reports, 3rd Party Test Data, Product Data
  Sheets also acceptable
On the Jobsite

• Product Labeling
  [IBC 2603.2 / IRC R316.2]
  – Containers on job site shall have mfg name, product ID, product listing, suitability for use

Get product data sheet, ESR and/or certification from builder/designer
[IRC N1101.8]

• Installation Certificate
  [IECC 401.3 / IRC N1101.8]
  – Provided by contractor to builder/homeowner
  – Thickness, R-value and product listing or data sheet
  – Placed on electric service panel or other conspicuous location
Summary

- Types of spray polyurethane foams
- Safety requirements
- Environmental impact
- Benefits
- Applications
- Building codes
Where can you learn more?

• SPFA Accreditation Training
• SPFA Website and Annual Conference
• Formulators and Systems House Suppliers
Thank You!

Questions?