Overview

- Introduction and history
- Discussion of rack storage testing
- Standards development discussion
Path to Defining Protection

- 2015 NFPA Conference
  - Palletized storage
    - 7 tier high in a 30 ft (9 m) roof
    - Leakage testing
    - Fire development
    - Water transport

Palletized Results

- Open area fraction is critical

Open area fraction = 6.7%
Open area fraction: 13.5 - 17%

Palletized Array Recommendation

- Open Area Fractions = 13.5 – 17%
  - Palletized storage of distilled spirits ≤ 75% alcohol
  - Stored up to seven tiers high in a 30 ft (9 m) roof
  - Ceiling only protection
    - Wet systems
      - K14.0 (K200), QR, 155°F (68°C), pendant sprinklers
    - Density = 0.60 gpm/ft² (24 mm/min)
Rack Storage

- Unknowns
  - Open area fraction
  - On-side barrel failure modes
  - Impact of greater ceiling heights – 40 ft (12 m)

Objectives

Find adequate protection for...

- 9-tier-high
- Rack-stored distilled spirits
- 75% or greater alcohol content
- Oak-wood barrels
- 40 ft (12 m) ceiling

Using...

- Wet (1) or dry (2) pipe ceiling only sprinklers, or
- In-rack sprinklers (3)

Rack Storage vs Palletized?

- Fire loading
- Barrel failure (vertical vs horizontal, barrels size)
- Open Area Fraction (water transport)
- Initial fire growth
- Effect of increased ceiling height
Fire Loading

Fire Loading Comparison

Single Barrel Tests
Single Barrel Tests

- Four barrel sizes tested

- 54 gal (200 L)
- 80 gal (300 L)
- 92 gal (350 L)
- 132 gal (500 L)

Barrel protection is an industry-wide problem

Barrel Surface Analysis

- 100% HD Camera
- 50/50
- 100% IR Camera
Single Barrel Fire Test Results

Leak rate does not lead to "catastrophic" increase in heat release rate

Open Area Fraction

Open Area Fraction

156 in (396 cm)
Open area fraction range between 16-18%
Fire Development

Findings, Palletized Versus Rack-Stored

<table>
<thead>
<tr>
<th></th>
<th>Rack Stored (9 tier high)</th>
<th>Palletized (7 tier high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Loading, BTU/ft² (MJ/m²)</td>
<td>3.4 x 10⁶ (3.8 x 10⁶)</td>
<td>5.8 x 10⁶ (6.6 x 10⁶) +74%</td>
</tr>
<tr>
<td>Fire Loading, gal/ft² (L/m² )</td>
<td>79 (1945)</td>
<td>129 (3173) +63%</td>
</tr>
<tr>
<td>Open Area Fraction</td>
<td>16%-18%</td>
<td>7%-17% ~Similar</td>
</tr>
<tr>
<td>Fire Growth</td>
<td>Comparable</td>
<td></td>
</tr>
</tbody>
</table>

Ceiling Height

<table>
<thead>
<tr>
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<th>Rack Stored (9 tier high)</th>
<th>Palletized (7 tier high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling Height, ft (m)</td>
<td>40 (12)</td>
<td>30 (9.1) -25%</td>
</tr>
</tbody>
</table>

Increased ceiling height would impose the greatest uncertainty. Higher ceilings require higher water flows.
Selection of Initial Protection Point

- Protect barrels under a 40 ft (12 m) ceiling
  - Ceiling only, wet pipe protection
  - Flow set to 0.85 gpm/ft² (34 mm/min)
  - K14.0 (K200) or greater orifice FM-Approved sprinklers with a 165°F (74°C) operating temperature.

- This protection option requires a full scale validation test.
Large-Scale Test Design, Commodity

- Wood type: Oak
- Formula: $\text{C}_{1.7} \text{H}_{0.72} \text{O}_{0.01}$
- Density: 35 lb/ft$^3$ (560 kg/m$^3$)
- $H_{comb}$: 7,300 BTU/lb (17.1 kJ/g)
- Capacity: 59 gal (225 L)
- Length: 37 in. (94 cm)
- Head diameter: 23 in. (58 cm)
- Bilge diameter: 27 in. (68 cm)
Additional Single Barrel Testing

Large-Scale Test Design, Test 1

**Test 1**
- K-factor: 14 gpm/psi\(1/2\) (200 lpm/bar\(1/2\))
- Orientation: Pendent
- RTI: 45 ft\(1/2\) s\(1/2\) (25 m\(1/2\) s\(1/2\)), QR
- Temperature rating: 165 F (74 C)
- # sprinklers installed: 64
- Sprinkler spacing: 10 ft x 10 ft (3.0 m x 3.0 m)
- Discharge pressure: 37 psi (2.6 bar)
- Per sprinkler discharge: 85 gpm (322 lpm)
- Design density: 0.85 gpm/ft\(2\) (34 mm/min)

Large-Scale Test Design

Tier 1-4
 Tier 5-7
 Tier 8-9

4510 gal (17000 L) of 75/25% mixture
Large-Scale Test Design

- 72 in. x 72 in pan (1.8 m x 1.8 m)
- 100% ethanol
- 20 gal (76 L) spill
- Centered among 4 sprinklers

Large-Scale Result, Test 1

- Protection design for first test
- Test 2
- K-factor: 16.8 gpm/psi^{1/2} (240 lpm/bar^{1/2})
- Orientation: Upright
- RTI: 214 ft^{1/2}s^{1/2} (118 m^{1/2}s^{1/2}), SR 286 F (141 C)
- # sprinklers installed: 64
- Sprinkler spacing: 10 ft x 10 ft (3.0 m x 3.0 m)
- Discharge pressure: 25 psi (1.7 bar)
- Per sprinkler discharge: 85 gpm (322 lpm)
- Design density: 0.85 gpm/ft^2 (34 mm/min)
- Delay: 40 seconds

Large-Scale Design, Test 2 (Dry Pipe)
Large-Scale Result, Test 2

Protection design for first test

Test 3, Ceiling
- K-factor: 11.2 gpm/psi^{1/2} (160 lpm/bar^{1/2})
- Orientation: Upright
- RTI: 199 ft^{1/2}s^{1/2} (110 m^{1/2}s^{1/2}), SR
- Temperature rating: 286\(^\circ\)F (141\(^\circ\)C)
- # sprinklers installed: 64
- Sprinkler spacing: 10 ft x 10 ft (3.0 m x 3.0 m)
- Per sprinkler discharge: 30 gpm (114 lpm)
- Design density: 0.3 gpm/ft\(^2\) (12 mm/min)
- Time delay: 40 seconds

Large-Scale Design, Test 3 (IRAS)

Test 3, Ceiling
- K-factor: 11.2 gpm/psi^{1/2} (160 lpm/bar^{1/2})
- Orientation: Upright
- RTI: ~45 ft^{1/2}s^{1/2} (~25 m^{1/2}s^{1/2}), QR
- Temperature rating: 155\(^\circ\)F (68\(^\circ\)C)
- # sprinklers installed: 13
- Sprinkler spacing: 4 ft (1.2 m) on line
- Per sprinkler discharge: 45 gpm (170 lpm)
- Time delay: 40 seconds

Large-Scale Design, Test 3 (Dry Pipe)

Test 3, IRAS
- K-factor: 8.0 gpm/psi^{1/2} (115 lpm/bar^{1/2})
- Orientation: Upright
- RTI: ~45 ft^{1/2}s^{1/2} (~25 m^{1/2}s^{1/2}), QR
- Temperature rating: 155\(^\circ\)F (68\(^\circ\)C)
- # sprinklers installed: 13
- Sprinkler spacing: 4 ft (1.2 m) on line
- Per sprinkler discharge: 45 gpm (170 lpm)
- Time delay: 40 seconds
Large-Scale Design Test 3 (IRAS)

First/Last Ceiling Sprinkler Operation (min:s)  1:03/3:20  1:49/2:30  2:16/3:19
Total Ceiling Sprinklers Opened  4  15  3 (IRAS)
Peak Gas Temperature, °F (°C) and Time  497 (258) @ 1:03  1783 (973) @ 2:06  750 (399) @ 3:17
Maximum Steel TC Measurement and Time, °F (°C)  178 (81) @ 7:45  477 (248) @ 2:43  197 (92) @ 3:17
Test Termination Time Ignition (min:s)  30:00  10:00  12:00
Defining New Protection Standards

- Palletized storage arrangements
  - 7 tiers high
  - 30 ft (9 m) roof
  - On-end barrels
  - ≤ 75% alcohol

- Creating open area fraction
  - 13.5 - 17%
  - Mandatory flue spaces
    - 6 in (150 mm) between all pallet rows

- Aisle spill fire protection
  - Dual sprinkler design
    - 0.2 gpm/ft² (8 mm/min) over aisle + draft curtain
  - Band drums on pallet
    - One ceiling system

- Ceiling design
  - K14.0 (K200), QR, 165°F (74°C), pendent sprinklers
  - Density = 0.60 gpm/ft² (24 mm/min)

- Wet and dry sprinkler system designs
  - Wet systems
    - K14 (K200) / QR / 165°F (74°C)
  - Dry systems
    - K16.8 (K240) / SR / 286°F (140°C)
Defining New Protection Standards

- **Rack storage array**
  - 9 tiers high / 30 ft (9 m)
  - 40 ft (12 m) roof
  - On-side oak barrels
  - ≤ 75% alcohol

- **Standard metal frame rack**
  - Metal walkways
  - Open area fraction
    - 16-18%

- **Standard metal frame rack**
  - Ceiling only protection
    - Wet system
      - K14.0 (K200), QR, 169°F (76°C), pendent sprinklers
      - 37 psi (2.5 bar) / 0.85 gpm/ft² (34 mm/min)
    - Dry system
      - 40 second water delivery
      - K16.8 (K240), SR, 286°F (140°C), upright
      - 25 psi (1.7 bar) / 0.85 gpm/ft² (34 mm/min)
Defining New Protection Standards

- Standard metal frame rack
  - Ceiling + in-rack protection
    - Ceiling
      » Dry system (40 second delay)
      » K11.2 (K160), SR, 286°F (140°C)
      » 25 psi (1.7 bar) / 0.3 gpm/ft² (12 mm/min)
    - In-rack
      » 1 level above 8th tier / 30 ft (9 m)
      » Dry system (40 second delay)
      » K8.0 (K115), QR, 155°F (68°C)
      » 32 psi (2.2 bar) / 45 gpm (95 L/min)

- Extension to higher roof/storage heights
- Use a layer of in-rack sprinklers at a lower level

Defining New Protection Standards

- Standard metal frame rack
  - Ceiling + in-rack protection
    - Extension to higher roof/storage heights
    - Use a layer of in-rack sprinklers at a lower level

Defining New Protection Standards

- Rack storage array
  - Rick type
    » Wooden frame, multiple floors
    » Wooden walkways
    » Loading aisle
    » Sample aisles
Defining New Protection Standards

- Rick storage array
  - Ceiling + in-rack protection
    - Wooden walkways
      - IRAS below all
      - Horizontal fire spread
    - Metal grate walkways
      - Use metal rack in-rack design
      - Sprinklers below loading aisles

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