EMISSIONS TESTING OF SONIC FLARES

Scot Smith, Director, Zeeco, Inc. Flare Division
Multipoint Ground Flare History

• Developed early 1970’s
• Zeeco founder was one of the original inventors and listed on original patent
• Original installation in 1972
• Many improvements over past 35 years in burner technology
• Basic overall concept today is same as original
Original Multipoint Flare Drawings
Burner Development Over 35 Years
Common Burner Characteristics

- Use jet action of gas to entrain air for smokeless burning
- Smokeless burning over wide pressure ranges
- Low radiation
- Stable operation at sonic velocity
- Multiple burners for unobstructed air access
Modern Sonic Velocity Burners

- Variable arm area
- Investment cast
- Pressure tested at factory
- 310 SS cast material
- Inherently stable on wide range of gases
Common MPGF Design Concept

• Many small burners
• Staging system ensures operation in optimum pressure band
• Number of burners in service are proportional to gas flow
• Typically used for high pressure, heavy hydrocarbon service
• Allows for controlled flame length from burners
Typical Staging Curve

Staging Curve

- Pressure Relief Valve
- All Valves Open

Flare Gas Pressure vs. Flare Gas Flow Rate
Typical Installations
Typical Installations
1983 CMA Testing

• Air-assisted flare
• Un-assisted flare
• Steam-assisted flare
• Extractive sampling
• EPA involvement
• Basis for current flare regulations, 40 CFR 60.18
1983 CMA Testing

• Subsequent to all CMA sponsored testing of flare systems, there was a separate test using the same equipment on a pressure-assisted flare tip

• Results of that test were submitted to the EPA

• Results showed very high destruction efficiency
1983 CMA Test Data on Pressure-Assisted Tip Testing, Crude Propylene Firing
1986 EER Testing for EPA

• Further EPA sponsored testing on different type of flare tips
• Testing intended to analyze further gas mixtures, alternative gas types, etc.
• 3-inch nominal flare tip size for most tests
• Testing was performed on pressure-assisted commercially available high velocity flare tips, Commercial tips “E” and “F”
# 1986 EER Testing on Pressure-Assisted Flare Tips, Propane in Nitrogen

## Table 2-2

**COMMERCIAL 1.5 INCH DIAMETER Pressure-Assisted Head E. Test Results**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Actual Exit Velocity (ft/sec)</th>
<th>%Propane in Nitrogen</th>
<th>Low Htg Val (Btu/ft³)</th>
<th>ΔP Across Head (psig)</th>
<th>Probe Ht (ft)</th>
<th>Wind Speed (mph)</th>
<th>Flame Length (ft)</th>
<th>Lift Off (in)</th>
<th>Color</th>
<th>Smoke</th>
<th>Sound</th>
<th>Comb Eff (%)</th>
<th>Hydro Carbon Dest Eff (%)</th>
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<td>14.3</td>
<td>15.8</td>
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<td>514</td>
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<td>7</td>
<td>2.5</td>
<td>2</td>
<td>yellow-purple base</td>
<td>none</td>
<td>dull rumble-roar</td>
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<td>95.1</td>
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<td>6</td>
<td>20</td>
<td>3</td>
<td>yellow-blue</td>
<td>none</td>
<td>loud roar</td>
<td>99.4</td>
<td>99.7</td>
</tr>
</tbody>
</table>
Testing by DOW for Two Installations

- Sonic velocity multipoint ground flares
- Two different applications, 2007 and 2014
- Nominal 4-inch spider type sonic burners
- General test results presented at AFRC Meetings
Combustion stability is a major factor in flare burner performance. A well designed and properly operated pressure-assisted flare burner with a stable flame will achieve 99+% DRE, which is the same or better than the efficiency of those flares that meet the requirements of Code of Federal Regulations, Title 40, Part 60.18.

Wind velocities up to 16 MPH (26 kph) had no identifiable impact on DRE results.
## DOW Pressure-Assisted Tip Testing, AFRC Presentation 2014

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pressure Assisted Tests</th>
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<tbody>
<tr>
<td>Test ID</td>
<td>P1H</td>
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<tr>
<td>Combustion Efficiency (%)</td>
<td>99.98</td>
</tr>
<tr>
<td>THC DE (%) (Based on O2 F-Factor)</td>
<td>99.98</td>
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<tr>
<td>Propylene DE Direct (%) (Based on O2 F-Factor)</td>
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<td>Propylene DE Bag (%) (Based on O2 F-Factor)</td>
<td>99.92</td>
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<tr>
<td>Critical Pressure (psig)</td>
<td>10.7</td>
</tr>
<tr>
<td>Pressure at Flare Tip (psig)</td>
<td>13.5</td>
</tr>
<tr>
<td>Exit Velocity at Flare Tip (ft/s)</td>
<td>880</td>
</tr>
<tr>
<td>Fuel Gas LHV (BTU/SCF) (GC Analysis)</td>
<td>2,145</td>
</tr>
<tr>
<td>Fuel Gas Flow Rate (lb/hr)</td>
<td>8,307</td>
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<tr>
<td>Combustion Efficiency (%) via PFTIR</td>
<td>99.8</td>
</tr>
</tbody>
</table>

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Approved for External Release
Sonic Flare Full Scale Testing for Smokeless / Flame Length / Crosslighting
Multipoint Flare Burner Testing
Multipoint Sonic Flare Testing at Zeeco for DRE

- Natural Gas
- Propylene
- Propane
- Inert / H2 Mixtures
- Consistently over 99.5% DRE
- Summer 2013 - Spring 2015
Multipoint Sonic Flare Testing at Zeeco
Testing Methods Used

Several Methods Used for Data Verification:

1. Extractive Sampling
2. PFTIR Analysis
3. Optical Efficiency Monitor Device (FlareSentry™)
Testing Methods Used

1. Extractive Sampling
   - Sample hood with venturi suction
   - Same design as TCEQ / TU tests 2010
   - Temperature and FLIR camera for positioning
Testing Methods Used

2. PFTIR Analysis
   - Common industry test-method
   - Monitoring relies on operator control
Testing Methods Used

3. Optical Efficiency Monitor Device (FlareSentry™)
   • New technology to directly, autonomously, and continuously monitor flare performance in real time
   • Requires no operator input

Imager for FlareSentry™; (Developmental platform; not final product)
Testing Methods Used

3. Optical Efficiency Monitor Device (FlareSentry™)
Test Area Video
Details for Zeeco’s Recent Sonic Testing

• Over 70 test points run
• Test gases ranged from 6 to 44 MW
• NHV ranged from 440 to 2316 BTU/SCF
• Operating pressures ranged from 3 to 30 psig
• Mixtures included Propylene, Natural Gas, Propane, H2, CO2, N2
Destruction Efficiency, Sonic Velocity

Destruction Efficiency vs Flare Gas Exit Velocity

- Measured Destruction Efficiency from Extractive Sampling
- Assumed Destruction Efficiency of 40 CFR 60.18
- Maximum Allowable Exit Velocity per 40 CFR 60.18
Combustion Efficiency, Sonic Velocity

Combustion Efficiency versus Flare Gas Exit Velocity

- Measured Combustion Efficiency from Extractive Sampling
- Measured Combustion Efficiency from IMACC PFTIR technology
- Maximum Allowable Exit Velocity per 40 CFR 60.18

Combustion Efficiency (%)

Flare Gas Exit Velocity (ft/s)
Comparison of FlareSentry, PFTIR, and Extractive Sampling Data

<table>
<thead>
<tr>
<th>Gases</th>
<th>C3H8</th>
<th>C3H8/N2</th>
<th>C3H6</th>
<th>NG</th>
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<tbody>
<tr>
<td>NHV (BTU/SCF)</td>
<td>2316</td>
<td>1251</td>
<td>2183</td>
<td>937</td>
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<tr>
<td>40 CFR Maximum Allowable (ft/s)</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Exit Velocity (ft/s)</td>
<td>841.4</td>
<td>969.9</td>
<td>869.8</td>
<td>1443.5</td>
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<tr>
<td>Mach Number</td>
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<td>1.00</td>
<td>1.00</td>
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<tr>
<td>Flare Operating Pressure (psig)</td>
<td>16.0</td>
<td>10.3</td>
<td>16.9</td>
<td>15</td>
</tr>
<tr>
<td>CE (%) from Extractive Sampling</td>
<td>99.99%</td>
<td>99.99%</td>
<td>99.96%</td>
<td>99.99%</td>
</tr>
<tr>
<td>CE (%) from PFTIR</td>
<td>99.60%</td>
<td>99.90%</td>
<td>99.60%</td>
<td>99.50%</td>
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<td>DRE (%) from Extractive Sampling</td>
<td>99.99%</td>
<td>99.99%</td>
<td>99.99%</td>
<td>99.99%</td>
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<tr>
<td>DRE (%) from FlareSentry™</td>
<td>99.80%</td>
<td>99.55%</td>
<td>99.90%</td>
<td>99.70%</td>
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</table>
CFD Analysis
CFD Analysis
General Benefits for MPGF

• **High destruction efficiencies**  
• Maximum **smokeless capacity** possible  
• **Low utility** usage and cost  
• **Minimizes impact** to your neighbors  
  – Radiation fence  
  – Smoke eliminated  
• **Easy access** for maintenance  
• **Small plot** space
Questions?