Experimental development of propane burners for fast cook off testing

2013 Insensitive Munitions and Energetic Materials Symposium

San Diego, California

October 5-8 2013

Jon Yagla PhD, David Griffiths, and David Hubble PhD
Naval Surface Warfare Center, Dahlgren, Virginia

Kevin Ford and Ephraim Washburn PhD
Naval Air Warfare Center, China Lake, California

Distribution Statement A: Approved for Public Release; Distribution is Unlimited
Current Propane Test Beds

- **Liquid Injection**
  - Meppen, Germany
  - China Lake, USA

- **Pre-Mixed Injection**
  - ‘t Harde, Netherlands
  - Bofors, Sweden

- **Gaseous Injection**
  - Dahlgren, USA

Distribution Statement A: Approved for Public Release; Distribution is Unlimited
Status of Gas Fired Fast Cook Off Testing Initiative

Until 2010: Skeptical community

2010 FFE Meeting in Meppen: Dr. Eich paper showing *temperatures and heating rates* were actually higher in a propane fire than a comparable kerosene fire

2010 IM/EM Symposium in Munich: Toreheim paper showing very *similar reactions* in propane and liquid fuel for 40mm gun ammunition and shoulder fired anti-tank rocket launcher

2012 IM/EM Meeting in Las Vegas: Dahgren /China Lake paper showing nearly *equivalent temperatures and heating rates* in a large JP-5 fire and Meppen propane fire

2012 FFE Meeting in Bordeaux: Propane and liquid fuel produce *comparable HF data* and *uniformity of spatial heating*. 100-150 kW/m² heat flux is a mandatory requirement for calibration testing.

2013 FFE ‘t Harde: Reaffirmed 100-150 kW/m² heat flux, developed a specification for testing with propane & requirement for facility calibration

Distribution Statement A: Approved for Public Release; Distribution is Unlimited
Agenda

Requirements definition

Discussion of heat flux

Instrumentation overview

Show through measurements and computer simulation how requirements are met

Summarize and conclude
AOP-39: “Where environmental concerns dictate, alternate fuel such as propane or natural gas may be used if testing verifies that the overall heat load to the test item matches what would be achieved from a liquid fuel fire at the established ramp and average temperature. For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the radiative conditions should match that of a liquid fuel fire”

STANAG 4240: “In the standard liquid fuel/external fire test, the test specimen is surrounded by fuel rich flames from a large open hearth containing liquid fuel. The large horizontal dimensions of the hearth ensure that the flames are fuel rich and hence heat transfer to the test specimen is approximately 90% radiative.”

2010 Fuel Fire Experts Meeting: The concerns of the international community are uniformity of heating, proportionality between radiation and convection, and the importance of soot
Define Thermal Requirements

From the above we derived a requirements statement to guide the design of a propane burner for fast cook off testing:

The overall heat load to the test item matches what would be achieved from a liquid fuel fire

The heating must be uniform

The heating should be approximately 90% radiative

The above must be verified by testing
Heat Flux

\[
\frac{\text{heat}}{\text{area}} = \text{kW/m}^2
\]
Fast cook, slow cook, and heat flux

Thermal Runaway on Centerline

Thermal Runaway at Interior Points

For high heat flux the ignition is at the outer surface

The time to cook off varies inversely with the heat flux

This shows

\[ T_{\text{ignition}} = \frac{100 \text{ min}}{\text{Heat Flux}} \]

(A casing and insulation can reduce the heat flux at the explosive below the incident value)
Heat Flux Instrumentation – PTs and DFTs

Plate Thermometer – PT
ISO 834-1:199(E)

Pros
• Standard, accepted method
• Robust and relatively cheap

Cons
• Complicated post processing
• Sensitive to noise

Directional Flame Thermometer – DFT
ASTM E-1529

Inconel plates
Type K thermocouples welded to centers of inner surfaces

Insulation

Pros
• Standard, accepted method
• Robust and relatively cheap

Cons
• Complicated post processing
• Sensitive to noise

Distribution Statement A: Approved for Public Release; Distribution is Unlimited
High Temperature Heat Flux Gage (HTHFG) - VT

- Thermopile measures temperature drop
- Temperature drop is proportional to heat flux
Instrumentation Arrangement

- 19” x 11” x 7”
- Used in Dahlgren JP5 fire, Meppen propane fire, Dutch liquid fuel fire, and Dutch propane fire
Directional Slug Calorimeter

- Developed in G65
- Heat flux from temperature measurements
- Robust and easily repaired
- Patent application submitted

\[
q_{in} - q_{out} - q_{cond} = mC \frac{\partial T}{\partial t}
\]
Paired thermocouples of different diameters were used to calculate the heat flux incident on a rocket motor.

Fabien Chassagne, “Fast Cook Off Test: Liquid Propane Gas vs Kerosene Pool Fire,” DGA/DT/CAEPE,
Test Objective

Verify by testing the thermal requirements are met:

• The overall heat load to the test item matches what would be achieved from a liquid fuel fire

• The heating is uniform

• The proportionality between radiation and convection is approximately 90% radiative
Standardized Instruments in a Fire

Instrumentation in a gasoline / diesel fuel fire in, ‘t Harte, The Netherlands

Basket of instruments

Distribution Statement A: Approved for Public Release; Distribution is Unlimited
Summary of data from six fires

<table>
<thead>
<tr>
<th>Fire</th>
<th>Fuel</th>
<th>Average Temperature</th>
<th>Temp s.d.</th>
<th>Average Heat Flux</th>
<th>Heat Flux s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>JP-5</td>
<td>927</td>
<td>32</td>
<td>139</td>
<td>5</td>
</tr>
<tr>
<td>France</td>
<td>Kerosene</td>
<td>959</td>
<td>13</td>
<td>139</td>
<td>16</td>
</tr>
<tr>
<td>France</td>
<td>Kerosene</td>
<td>981</td>
<td>35</td>
<td>156</td>
<td>5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Diesel/Gasoline</td>
<td>987</td>
<td>15</td>
<td>113</td>
<td>20</td>
</tr>
<tr>
<td>Germany</td>
<td>Propane</td>
<td>1028</td>
<td>131</td>
<td>136</td>
<td>5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Propane</td>
<td>1211</td>
<td>19</td>
<td>127</td>
<td>25</td>
</tr>
</tbody>
</table>
The heat flux is in the range 100 – 150 kW/m²
Computer Model of Propane Fire

National Institute of Standards and Technology “Fire Dynamics Simulator” computer simulations

Fabien Chassagne, “Fast Cook Off Test: Liquid Propane Gas vs Kerosene Pool Fire,” DGA/DT/CAEPE,
Computer results with data from standard instrumentation in basket in Meppen fire

*The heat flux is 90% radiative*

(Fabien Chassagne, DGA)
Thermocouple Grid and Temperature Fields

Grid with 50 thermocouples

Temperature field in ‘t Harde propane fire

The heating is uniform
Summary and Conclusions

• Propane burners meet STANAG temperature rise and average requirements
• Propane burners meet the new heat flux requirements
• Propane burners provide mostly radiative heating as in liquid pool fires
• Burners must be analyzed to determine volume within the fire meeting requirements