Novel ARDEC Igniters for Gun Systems

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**Problems:**

- Benite doesn’t perform as well as BKNO$_3$ in 120MM tank rounds
- Benite gives inconsistent performance results.
- Future rounds need smaller igniter tubes.

**Solution:**

- ARDEC has developed an igniter formulation
  - Excellent and consistent performance
  - Less sensitive than Benite
  - Is more energetic than Benite
  - Extrudable
  - Smaller Ignition Delays
Possible Causes:

- Type IV BKNO₃ igniter has an oxygen balance of -35%:
  - After firing, all of the oxygen in the barrel is exhausted.
  - Boron combustion requires large amounts of oxidizer.
  - Opening of breach allows a rapid influx of oxygen which ignites uncombusted boron (or other fuel).

BKNO₃

- Made of:
  - 70% Potassium Nitrate
  - 30% Boron
- Easily ignited at low P.
- High Gas Content
- Burn Rate insensitive to P.
- Hygroscopic (less than Black Powder)
- Flare Back (Incomplete oxidation)

Benite

- Made of:
  - 40% Nitrocellulose
  - 6.3% Sulfur
  - 44.3% Potassium Nitrate
  - 9.3% Charcoal
  - 0.5% Ethyl Centralite
- Performance as an igniter is adequate for tank applications.
Properties of Binders Considered

Nitrocellulose
\[ \rho = 1.66 \text{ g/cc} \]
\[ \Delta H_f = -690 \text{ kJ/mol} \]
\[ T_v = 3331 \text{ K} \]
O.B. = -31%

Cellulose Acetate/Butyrate
\[ \rho = 1.22 \text{ g/cc} \]
\[ \Delta H_f = -1630 \text{ kJ/mol} \]
\[ T_v = 1052 \text{ K} \]
O.B. = -160%

Glycidyl Azide Polymer (GAP)
\[ \rho = 1.29 \text{ g/cc} \]
\[ \Delta H_f = 176 \text{ kJ/mol} \]
\[ T_v = 2288 \text{ K} \]
O.B. = -121%

poly-Bis-AzidoMethyl-Oxetane
\[ \rho = 1.30 \text{ g/cc} \]
\[ \Delta H_f = 373 \text{ kJ/mol} \]
\[ T_v = 2246 \text{ K} \]
O.B. = -124%

FNGUN Analysis

- Instantaneous Ignition along the igniter tube.
- No Pressure Differentials.

- Staged Ignition from the middle of the igniter tube.
- -50 MPa Pressure Differentials.
Sensitivity Analysis

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Igniter Sensitivity</th>
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<tbody>
<tr>
<td></td>
<td>Impact ERL (cm)</td>
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<tr>
<td>Benite</td>
<td>18.8</td>
</tr>
<tr>
<td>BKNO3</td>
<td>23.2</td>
</tr>
<tr>
<td>PAI-8556</td>
<td>22.4</td>
</tr>
<tr>
<td>PAI-8557</td>
<td>24.6</td>
</tr>
<tr>
<td>PAI-8558</td>
<td>&gt;100</td>
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</table>

### Critical Diameter

<table>
<thead>
<tr>
<th>Lot #</th>
<th>Diameter</th>
<th>Result</th>
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<tbody>
<tr>
<td>8551</td>
<td>0.1345</td>
<td>NOGO</td>
</tr>
<tr>
<td>8551</td>
<td>0.1350</td>
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<tr>
<td>8558</td>
<td>0.1405</td>
<td>NOGO</td>
</tr>
<tr>
<td>8558</td>
<td>0.1415</td>
<td>NOGO</td>
</tr>
<tr>
<td>8556</td>
<td>0.1420</td>
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<tr>
<td>8556</td>
<td>0.1440</td>
<td>NOGO</td>
</tr>
<tr>
<td>8557-3</td>
<td>0.1400</td>
<td>NOGO</td>
</tr>
<tr>
<td>8557-3</td>
<td>0.1385</td>
<td>NOGO</td>
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</table>

### Small Scale Burn

<table>
<thead>
<tr>
<th>Material</th>
<th>Burn Time</th>
<th>Explosion</th>
<th>Detonation</th>
<th>Pass/ Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAI-8556</td>
<td>Less 1 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
<tr>
<td>PAI-8557</td>
<td>Less 1 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
<tr>
<td>PAI-8558</td>
<td>Less 1 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>2.01 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>2.79 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>3.05 Sec.</td>
<td>NO</td>
<td>NO</td>
<td>Pass</td>
</tr>
</tbody>
</table>

### Thermal Stability

<table>
<thead>
<tr>
<th>Material</th>
<th>Starting Weight</th>
<th>Total Loss</th>
<th>Pass - Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAI 8556</td>
<td>50.4135gms</td>
<td>.1464gms</td>
<td>PASS</td>
</tr>
<tr>
<td>PAI 8557</td>
<td>50.2485gms</td>
<td>.2614gms</td>
<td>PASS</td>
</tr>
<tr>
<td>PAI 8558</td>
<td>50.2745gms</td>
<td>.1545gms</td>
<td>PASS</td>
</tr>
</tbody>
</table>
Benite at Ambient Temperature

- Ambient Temperature.
- 5 shots
- P never returned to zero
- No Negative Pressure Differentials
PAI-8557 Un-Ground BKNO₃

![Graph showing pressure over time for different sensors.]

- Benite Sensor 1
- Benite Sensor 2
- PAP-8557-3 Stick Shot 2 Sensor 1
- PAP-8557-3 Stick Shot 2 Sensor 2
- PAP-8557-3 Stick Shot 4 Sensor 1
- PAP-8557-3 Stick Shot 4 Sensor 2

Analysis of $P_{\text{max}}$ and $t_2$

The graph shows the analysis of peak pressure ($P_{\text{max}}$) and time ($t_2$) for different samples:

- Benite 21C S1
- PAI-8556-2 S1
- PAI-8556-6 S1
- PAI-8557 S1
- Benite 21C S2
- PAI-8556-2 S2
- PAI-8556-6 S2
- PAI-8557 S2

The x-axis represents $P_{\text{max}}$, $\Delta P_{\text{max}}$, $t_2$, and $\Delta t_2$, while the y-axis shows the values for each category.
Analysis of $t_5$ and $t_6$
Analysis of $t_{h1}$, $t_{h2}$, and $t_h$
High Speed Video Stills of Benite Igniter at Ambient Temperature
High Speed Video Stills of PAI-8556 at Ambient Temperature
<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Image Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Initial state</td>
</tr>
<tr>
<td>0.3</td>
<td>State 1</td>
</tr>
<tr>
<td>0.8</td>
<td>State 2</td>
</tr>
<tr>
<td>1.3</td>
<td>State 3</td>
</tr>
<tr>
<td>1.8</td>
<td>State 4</td>
</tr>
<tr>
<td>4.7</td>
<td>State 5</td>
</tr>
<tr>
<td>5.6</td>
<td>State 6</td>
</tr>
<tr>
<td>6.8</td>
<td>State 7</td>
</tr>
</tbody>
</table>
Conclusions

- Benite was found to have significant shot to shot variability in terms of pressure and time.
- Extrudable BKNO$_3$ analogue igniters were able to achieve $P_{\text{max}}$ faster than benite with less variance in ignition delays and output pressures than benite demonstrating that the analogue igniters are more consistent.
- High speed video of the ignition events also demonstrated more hot particle and flame generation in the BKNO$_3$ analogue igniters in comparison to benite.