FOX-7, an IM Ingredient Candidate – Where Are We Today?

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Outline

- Why new Energetic Molecules
- FOX-7 Basics
- FOX-7 Crystals
- FOX-7 Formulations and Applications
- Conclusions
Ways to Insensitive Munitions..

- Modify the energetic material
- Modify the composition
- Modify the munition
- Modify the ammunition depot or storage
- Modify the packaging
Ways to Insensitive Munitions..

- Modify the energetic material
- Modify the composition
- Modify the ammunition depot or storage
- Modify the packaging

FOI activities
FOX-7

- 1,1-Diamino-2,2-dinitroethylene
- Developed at FOI in 1997--
- WO Patent No. 9903818
- Produced by EURENCO Bofors AB under licence by Swedish Government

\[
\begin{align*}
&\text{HNO}_3/\text{H}_2\text{SO}_4 \\
&\text{5-10°C} \\
&\rightarrow \\
&\text{H}^+, \text{H}_2\text{O} \\
&\rightarrow
\end{align*}
\]

88%
FOX-7 Basics

Low sensitivity explosives
Simple synthesis

Crystal Structure

Density (crist): 1.885 g/cm³
Heat of Formation: -32 kcal/mole
Sensitivity: drop weight 70 cm (RDX 38 cm)
friction > 350 N (RDX 120 N)
Explosion Temperature: 215 °C (RDX 220 °C)
Detonation Pressure (calc): 33.96 GPa (RDX 34.63 GPa)
Detonation Velocity (meas.): 8870 m/s (RDX 8930 m/s)

Synthesis

\[
\begin{align*}
\text{FOX-7} & \quad \text{HNO}_3/\text{H}_2\text{SO}_4 \\
& \quad \text{aq NH}_3
\end{align*}
\]
## Impact and Friction Sensitivity of FOX-7

<table>
<thead>
<tr>
<th>Sample</th>
<th>Drop height (cm)</th>
<th>Friction (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOX-7 (recryst., 250–355 μm)</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>FOX-7 (recryst., &lt; 70 μm)</td>
<td>63</td>
<td>&gt;340</td>
</tr>
<tr>
<td>RDX</td>
<td>38</td>
<td>126</td>
</tr>
</tbody>
</table>
FOX-7: DSC

$E_a = 234 \text{ kJ/mole (56 kcal/mole)}$

Heat Flow ($\mu$W)

Temperature (°C)

$\frac{1}{T}$

$\ln (R)$
FOX-7: SSGT

**EXPLOSIVE DENSITY (g/cc) Attenuator Thickness (mm)**

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetryl</td>
<td>1.65</td>
<td>8.36</td>
</tr>
<tr>
<td>HNS II</td>
<td>1.635</td>
<td>7.19</td>
</tr>
<tr>
<td>TNT</td>
<td>0.92*TMD</td>
<td>6.4</td>
</tr>
<tr>
<td>HMX</td>
<td>0.92*TMD</td>
<td>10.3</td>
</tr>
<tr>
<td>RDX</td>
<td>0.92*TMD</td>
<td>9.33</td>
</tr>
<tr>
<td>FOX-7</td>
<td>1.634</td>
<td>6.22</td>
</tr>
</tbody>
</table>
### FOX-7

#### Small-scale gap test

<table>
<thead>
<tr>
<th>Name</th>
<th>Density</th>
<th>Distance (50% probability point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOX-7</td>
<td>1.63 g/cm³ (86% of TMD)</td>
<td>6.2 mm</td>
</tr>
<tr>
<td>TNT</td>
<td>1.53 g/cm³ (92% of TMD)</td>
<td>6.4 mm</td>
</tr>
<tr>
<td>RDX</td>
<td>1.66 g/cm³ (92% of TMD)</td>
<td>9.3 mm</td>
</tr>
</tbody>
</table>

#### Air gap test

<table>
<thead>
<tr>
<th>Name</th>
<th>Density</th>
<th>Distance (50% probability point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>1.51 g/cm³ (91% of TMD)</td>
<td>34 – 35 mm</td>
</tr>
<tr>
<td>FOX-7</td>
<td>1.72 g/cm³ (91% of TMD)</td>
<td>35 – 37.5 mm</td>
</tr>
<tr>
<td>Composition B</td>
<td>1.59 g/cm³ (91% of TMD)</td>
<td>60 – 62.5 mm</td>
</tr>
</tbody>
</table>

FOX-7: Ignition Temperature
*(Wood’s metal bath)*

No reaction when $T < 215^\circ C$
(RDX ignites at $220^\circ C$)
FOX-7: KOENEN TEST
(Steel sleeve test)

Type “F” reaction at nozzle plate diameter 6 mm
RDX explodes at nozzle plate diameter 8 mm
FOX-7: Compatibility by HFC

\[ C_{ab} = E_{ab} \frac{E_a - E_b}{2} \]

Incompatible:
- \(C > 20\ J/g/week\)

Slightly Incompatible:
- \(10\ J/g/week < C < 20\ J/g/week\)

Compatible:
- \(C < 10\ J/g/week\)

<table>
<thead>
<tr>
<th>Polymer</th>
<th>(E_a) (J/g/week)</th>
<th>(C_{ab}) (J/g/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAB (BF900)</td>
<td>0.38</td>
<td>-0.38</td>
</tr>
<tr>
<td>Estane</td>
<td>0.27</td>
<td>-0.26</td>
</tr>
<tr>
<td>GAP (SNPE)</td>
<td>2.57</td>
<td>-0.44</td>
</tr>
<tr>
<td>HTPB (R-45 HT)</td>
<td>1.89</td>
<td>3.89</td>
</tr>
<tr>
<td>HTPB (Krasol LBH)</td>
<td>0.24</td>
<td>0.13</td>
</tr>
<tr>
<td>Viton</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Isocyanate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(H_{12}MDI)</td>
<td>0.70</td>
<td>0.41</td>
</tr>
<tr>
<td>Plasticizer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyl-NENA</td>
<td>1.07</td>
<td>0.16</td>
</tr>
<tr>
<td>K-10</td>
<td>0.41</td>
<td>0.44</td>
</tr>
</tbody>
</table>
Data for FOX-7 + 1.5 w% wax, \( \delta = 1.756 \, \text{g/cc} \) The detonation velocity was estimated to 8.335 \( \pm \) 0.025 mm/\( \mu \)s; A Cheetah calculation, BKWC, gave a velocity of 8.266 mm/\( \mu \)s, which is in good agreement with the experimental value.
FOX-7

Candidate for ingredients in
- Boosters
- Shape Charge warheads
- High performance warheads
- Rocket and gun propellants

Particle size and particle quality is very important for sensitivity and processing properties.
NSF 110 (20 – 40 µm) is the smallest particle size available which also gives a relatively low bulk density, < 0.6 g/cm³ according to Hall measurements. Below, a SEM-photo with a 1000 times magnification is shown together with a particle size distribution measured by Malvern is shown.
NSF 120 (50 – 100 µm) gives a bulk density of approximately 0.7 g/cm³ according to Hall. The picture shows a 200 times magnification of the particles and a particle size distribution measured by Malvern.
NSF 130 (100 – 200 μm) gives a bulk density of approximately 0.85 g/cm³. The SEM photo is a 70 times magnification and the particle size distribution is a Malvern measurement.
NSF 140 (250 – 350 µm) is the largest particle size available at present. This quality has a bulk density of approximately 0.95 according to Hall. The SEM photograph is 70 times magnification and sieving results for a couple of batches are shown on the side.
Eurenco Bofors AB has produced nearly 1000 kg (7 kg batches, 1 to 3 per day) of FOX-7 in its own pilot plant.

- Molar yield 80% for nitration step
- Very small particle size has caused problems to wash the filter cake. A separate washing step has been introduced to obtain pure product.
- HPLC-purity is more than 99% for washed product.
Insensitive Formulations and Applications
Pressed Explosives

- Pressed FOX-7/wax (97.8/2.2 wt%)
- Investigated as an explosive for use in shape charge applications

A. Helte et al. 23rd Int Symp on Ballistics, Spain (2006)
Pressed Explosives

✓ Jet straightness
✓ Jet velocity
✓ Fragmentation time

FOX-7 > Comp B

✓ Penetration (ARMOX 300S)
  FOX-7  230 mm (2.9 cal)
  Comp B  265 mm (3.3 cal)

A. Helte et al. 23rd Int Symp on Ballistics, Spain (2006)
FOF-2

- FOX7 (255-350mm) 50 wt%
- FOX7 (< 70mm) 20 wt%
- PolyGlyN 21 wt%
- Butyl-NENA 5 wt%
- H12MDI (Desmodur-W) 4 wt%
- DBTDL 0.03 wt%

- Tg = -35°C
- Thermally stable at 65°C (14 days)
Small-scale slow cook-off

100-400°C
Heating rate: 3.3°C/hour
Small-scale slow cook-off - Results

RDX/TNT 60/40

\( T_{\text{cook-off}} \) 207°C (Type I reaction)

FOF-2

\( T_{\text{cook-off}} \) 220°C (Type V reaction)
A New Explosives Formulation - FOF-5

- FOX-7 (238µm) 38.1%
- FOX-7 (32µm) 25.4%
- HMX (22 µm) 16.5%
- Energetic binder 20%
  - PolyGlyN 7.2%
  - GAP 7.2%
  - Butyl-NENA 3.6%
  - H_{12}MDI (Desmodur-W) 2.0%
  - DBTDL
Slow Heating (Slow Cook-Off)

First test (inert fuze) ⇒ Type V response (fire)
Second test (HNS II-based fuze) ⇒ Type IV response (deflagration)

Composition B ⇒ Type I response (detonation)
Fast Heating/Fuel Fire (Fast Cook-Off)

- Blast pressure (max 160 Pa) and no significant heat radiation
  - Type IV response (fire)
- Debris (fuze) recovered at > 24 meters from test stand
  - Type IV response (deflagration)
- Composition B
  - Type I response (detonation)
Debris (fuze) recovered less than 15 meters from test stand

⇒ Type V response (fire)

*Composition B* ⇒ *Type I response (detonation)*
A Potential IM Explosive?

- FOF-5 is a cast-cured explosive based on FOX-7 and HMX with the same performance (calc.) as Composition B (RDX/TNT 60/40).

- Initial IM testing of ammunition containing FOF-5 - results:

<table>
<thead>
<tr>
<th></th>
<th>Slow Cook-Off</th>
<th>Fast Cook-Off</th>
<th>Bullet Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOF-5</td>
<td>Fire (1st test)</td>
<td>Deflagration</td>
<td>Fire</td>
</tr>
<tr>
<td>(Batch No. 1)</td>
<td>Fire/Defl (2nd test)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition B</td>
<td>Detonation</td>
<td>Detonation</td>
<td>Detonation</td>
</tr>
</tbody>
</table>
**Composite propellants**

- FOX-12/RDX and FOX-7/HMX based compositions
- Energetic binder
Low Sensitivity Explosives HE

TATB

LLM-105

NTO

FOX-12

FOX-7

Low Sensitivity Explosives HELow Sensitivity Explosives HE

TATB

LLM-105

NTO

FOX-12

FOX-7

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Conclusions

- FOX-7 is very insensitive.
- FOX-7 makes it possible to produce low sensitivity charges with high performance, as exemplified by the shaped charge and 40mm small caliber examples.
- The availability of more and better characterized particle sizes will enable an easier development of new low sensitivity, high performance applications.
- FOX-7 is available in large quantities.