**Ionic Liquids R&D at US Air Force Research Laboratory (Preprint)**

**Title and Subtitle**

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Ionic Liquids R&D at
US Air Force Research Laboratory
(PREPRINT)

USAF AFRL
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**Issues and Drivers**

- **Increased Testing and Operations Costs:**
  - System Handling/Fueling
  - Monitoring System in Field
  - Delays in Launch for Corridor
    - Hazardous/Carcinogenic Vapor (Respiratory Route)
    - Dermal Toxicity

- **Performance of SOTA Propellant**
  - Desire Improved Isp and D*Isp
    - Improved Capabilities (Payload and Range)
Energetic Ionic Liquids

• **Background**
  – An ionic compound that has a melting point at or below 100ºC
  – Seminal work at USAFA
  – Industrial solvents, green chemistry
  – Ionic Liquids current focus area of AFOSR

  **AFRL now leading energetic IL discovery/development**

• **Advantages as Energetic Materials**
  – Low vapor pressure, **low vapor toxicity**
  – High density
  – Physical and chemical properties can be tailored

Can adjust these properties by:
• Varying cation and anion
  – Size, shape, symmetry, composition, hydrogen bonding
• Creating mixtures, eutectics, etc.

Why ILs as Energetic Materials?

“Tuning” IL structure for:
- Energy content
- Oxygen balance
- Melting point
- Liquid range

Propulsion:
- Thrusters

Explosives:
- Melt-cast munitions

Power Plants:
- Power generators, APU's,....
**Why Ionic Liquids for Propulsion?**

- A figure of merit (FOM) can be based on the momentum imparted by a HEDM normalized by that of a standard material (e.g., NTO/MMH)
- Two main properties
  1) Average kinetic energy (KE) of gases produced per unit mass of HEDM combusted/decomposed
  2) Density ($\rho$) of material

**FOM**

$$FOM = \frac{\left(\frac{2KE_{HEDM}}{\rho_{HEDM}}\right)^{1/2} \ln(1 + c'\rho_{HEDM})}{\left(\frac{2KE_{STAND}}{\rho_{STAND}}\right)^{1/2} \ln(1 + c'\rho_{STAND})}$$

(Where, $c' = \frac{\text{Material volume/Mass of combustor}}{}$; and set to 1.0 m$^3$/kg)

<table>
<thead>
<tr>
<th>KE (MJ/kg)</th>
<th>NTO-HEHN</th>
<th>NTO-HEATN</th>
<th>NTO-MMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ (kg/m$^3$)</td>
<td>1424</td>
<td>1454</td>
<td>1189</td>
</tr>
<tr>
<td>FOM (STAND=NTO/MMH)</td>
<td>1.03</td>
<td>1.05</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**NTO-HEATN**

$$\left[\text{HOCH}_2\text{CH}_2\text{N}_2\text{H}_4\right]^+\text{NO}_3^-$$

HEATN; $\rho = 1.48$ g/cc; MP = 0C

**NTO-HEHN**

$$\text{H}^+\text{C}^+\text{N}^+\text{N}^-\text{N}^-\text{N}^-\text{CH}_2\text{OH}^-\text{NO}_3^-$$

HEHN; $\rho = 1.42$ g/cc; MP < -25C
Ionic Liquid Fuel for Bipropulsion

Goal: Demonstrate feasibility of ionic liquid as fuel for bipropellant systems

<table>
<thead>
<tr>
<th>Accomplishment</th>
<th>Significance</th>
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<tbody>
<tr>
<td>• AFRL/PRSP working with Purdue University has successfully tested high performance ionic liquid fuel in a bipropellant thruster</td>
<td>• Storable bipropellant system with potential increase in performance over NTO/MMH</td>
</tr>
<tr>
<td></td>
<td>• Greatly reduced toxicity vs NTO/MMH</td>
</tr>
<tr>
<td></td>
<td>‒ Using ionic liquid instead of MMH</td>
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<tr>
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<td>‒ Using hydrogen peroxide instead of NTO</td>
</tr>
</tbody>
</table>

Thruster during bipropellant operation (93% C* efficiency)

Staged bipropellant thruster for ionic liquid fuel

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Ionic Liquids in Munitions

- Triazolium salts initially synthesized at USAF
- Scaled to the 50 gram level and characterized in ONR program

1,2,4-triazolium perchlorate

4-amino-1,2,4-triazolium perchlorate (4-ATP)

4-amino-1,2,4-triazolium nitrate

1-amo-no-3-methyl-1,2,3-triazolium nitrate

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Energetic Ionic Liquids for TNT replacements

Very promising initial results!!

Shock velocity determination

- 4-ATP (melt cast) $\rho = 1.74 \text{ g/cm}^3$; shock velocity = 8.3 mm/usec
- TNT (pressed) $\rho = 1.63 \text{ g/cm}^3$; shock velocity = 6.9 mm/usec (LLNL Data)

4-ATP is approaching energy output of high melt point, state-of-the-art nitramines like RDX!

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