Advanced Propellant/Additive Development for Fire Suppressing Systems

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Outline of Presentation

• Introduction
  – Program Background Information
  – Fire Suppression and GG’s

• Propellant Development
  – Cooler, High Nitrogen Compositions

• Effectiveness Testing
  – SPFES (Solid Propellant Fire Extinguishers)
  – HFEs (Hybrid Fire Extinguishers)

• Summary

• Acknowledgements
But First…

GF Holland
PH Wierenga

S Fallis
R Reed

Olin Aerospace
Rocket Research
Fire Suppression Mechanistics

\[ \text{FE} = \text{X}_{\text{dil}} + \text{X}_{\text{cool}} + \text{X}_{\text{chem}} + \text{X}_{\text{flow}} \]

- \( \text{X}_{\text{dil}} \sim \text{dilution effects: } [\text{O}_2] \approx 12-13\% \)
- \( \text{X}_{\text{cool}} \sim \text{cooling effects: } C_p \approx 40-50 \text{ cal/}\degree\text{K-mol } \text{O}_2 \)
- \( \text{X}_{\text{chem}} \sim \text{chemical effects: radical traps} \)
- \( \text{X}_{\text{flow}} \sim \text{flow rate effects: dec } \tau_{\text{res}} \text{ in flame zone} \)
Solid Propellant Fire Suppression Systems

Current State of the Art:
- Size competitive w/ Halon-1301 (volume, mass)
- Effective, clean, fast acting
- Environmentally rugged and reliable
- Low human hazard: CO₂, N₂, H₂O
- Environmentally friendly, SNAP-approved
- Temperature compensating designs
- All based on commercial automotive airbag technology

Next Generation Objectives:

Improve effectiveness via:
- Increased cooling
  - Cooler burning propellants
  - Hybrid configurations
- Increased gas output
- Added chemical activity

Opportunity:
- 2-5x reduction in agent loads
Program Background Information: Propellant Development

• Phase I
  – Developmental Compositions, High-N Compounds
  – Chemically Active Formulations: vary agent

• Phase II
  – BTATZ Scale-up
  – Chemical additives incorporated into SPFE, HFE

• Phase III
  – BTATZ Formulations: Ballistic Testing
  – Chemically Active Formulations: vary [agent]
High-Nitrogen Fuels Used in CL/PAC Propellant Development

Guanidinium Bitetrazole (GBT)

Bisguanidinium Azotetrazole (GAZT)

Triaminoguanidium Nitrate (TAGN)

Bis(aminotetrazolyl)tetrazine (BTATZ)

5-Aminotetrazole (5AT)

Bitetrazole (BT)
Effect of Combustion Temperature on Ballistics

- Trends
  - BR not predictable by $T_c$ alone
  - Falloff in BR follows Arrhenius-type activated process
    - $\ln(BR) = f(1/T_c)$
    - Slopes vary
- Predictive tool?
Control of Exhaust Temperatures

- Propellant modifications
  - Vary F, O
    - F+O $\rightarrow$ CO$_2$, N$_2$, H$_2$O
  - Incorporate coolant
  - Calculate $T_c$ (combustion)
  - $T_{\text{meas}}$ $\sim$ 200–600 °C

- Hybrid combinations
  - $T_{\text{meas}}$ $\sim$ 50–100 °C

![Graph showing the relationship between MgCO3 % and $T_c$ °K.](image)

5-Aminotetrazole (5AT)

Bis(aminotetrazolyl)tetrazine (BTATZ)
# Developmental Propellants: High Gas, Cooler Gas

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Tc, °C</th>
<th>Gas, mol/100g</th>
<th>theoretical density, g/cc</th>
<th>BR&lt;sub&gt;1000&lt;/sub&gt;, in/s</th>
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Propellant Combustion

Discharging from GG
Rate of discharge = orifice \times P
Discharge is uniform blend of CO₂, N₂, H₂O + Additive

Evolving from propellant into GG at uniform rate:
CO₂+N₂+H₂O + additive Vapor + Heat
Rate of evolution = Area \times Burn rate

Initiator output ignites propellant

F+O → CO₂+N₂+H₂O + clinker + HEAT
HEAT flows into grain

Burn progresses uniformly into propellant
Rate = (const) \times P^n

Each propellant grain is a uniform mix of:
- Fuel (F, yellow matrix)
- Oxidizer (O, green)
- Coolant (blue)
- Additive (red diamonds)

Additive + HEAT → vaporization

Coolant + HEAT → CO₂ + Clinker
Aerojet Fire Test Fixture

Fuel Spray

SPGG or HFE on Bracket

Air Inlet
Test Fixture Parameters

• ~700 kW Flame Intensity
  – Flame temperature = ~1000 K (1300 °F)
  – Air flow rate = 450 g/s (1 lbₐir/s)
  – Fuel flow rate = 15 g/s (0.033 lbₐir/s)
  – Air:fuel ratio = 31
  – Equivalence ratio = 0.5

• 24 ft³ Total Volume (16 ft³ fire zone)
  – Residence time = ~1 s (through fire zone)

• 100-200 ms Discharge Time for SPFEs and HFEs

\[
\frac{m_{\text{air}}}{m_{\text{fuel}}}
\]
Aerojet SPFE Active Agent Test Unit

- Agent exhaust
- Matrix containing chemical particulate
- Solid Propellant
- Initiator
- Chamber 1
- Chamber 2
Test Videos: Active Agent Assessment

$\text{Fe}_2\text{O}_3/\text{FeCp}_2$  \hspace{2cm} $\text{KI}/\text{K}_2\text{CO}_3$
## Summary of FTF Data

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<th>Neat agent</th>
<th>Agent mass, g</th>
<th>Test No.</th>
<th>Result</th>
<th>Neat agent</th>
<th>Agent mass, g</th>
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</tbody>
</table>
SPFE’s

- Advantages
  - Rapid discharge
  - No storage pressure
  - T-compensating

- Applications
  - Ballistic & safety fire protection for aircraft.
  - Land vehicle engine compartments.
  - Electronics bays
Hybrid Fire Extinguishers

• Advantages
  – Tailorable discharge
  – Fits into current Halon 1301 envelope
  – Low/No storage pressure
  – T-compensating discharge

• Applications
  – Armored vehicle engine & crew compartments.
  – Aircraft engine nacelles.
  – Automotive & industrial fire/explosion protection
SPFE, HFE Testing

Fire Test, active agent

Discharge demo, active agent (100x)
3304/FM200 HFE Fire Out Sequence

HFE Function: T= 0 msec  T= 33 msec  T= 66 msec

T= 99 msec  T= 132 msec  T= 165 msec
Performance Summary

Mass of Initial Agent (g)

SPFE Baseline
HFE Baseline

Series: 10:1 – 6:1
Vary $T_{exh}(+1 \text{ ft})$ ~ 50–65 °C

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Conclusions

• BTATZ-based formulations provide excellent platform for cooler-burning FS compositions

• Increasing the amount of active additive leads to more efficient SPFE and HFE performance.
  – Catalysis not yet saturated

• HFE’s effective for low vapor pressure fluids
  – Higher-boiling fluorocarbons
  – Water-based systems
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