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Update on HTPE Propellant Service Life

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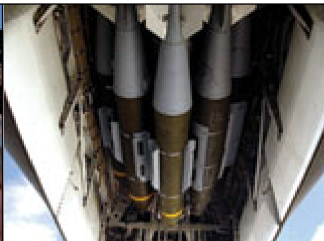


Background for HTPE Propellants

- **Based on hydroxyl-terminated polyether (HTPE) polymer manufactured by ATK**
  - **Uses ammonium perchlorate and ammonium nitrate oxidizers and BuNENA plasticizer**
- **Under development and production by ATK for over 20 years**
- **ATK developed tactical aluminized and reduced smoke HTPE propellants for improved insensitive munitions (IM) response**
  - **Rocket motors manufactured from HTPE propellants have demonstrated improvements in IM performance**
  - **HTPE passed 6-inch diameter zero card gap test**
    - **non-detonable for motors with webs up through six inches**
- **Over 1000 HTPE propellant mixes of various sizes and over 2500 motors manufactured**

HTPE Service Life Database

- **Over 90 separate HTPE propellant mixes have been aged at various temperatures for stabilizer content and/or mechanical property measurements**
  - **Gas generation and burning rates have also been measured on some propellants**
- **Many direct comparison measurements have been made to deployed tactical minimum smoke propellants which demonstrate that HTPE propellants have equal or longer service life**
  - **Over 40 propellant mixes aged at 165°F (74°C) the standard database temperature for minimum smoke propellant aging**
- **Long-term aging study being conducted on HTPE propellant**
  - **15-year aging data presented**

HTPE Compared to Minimum Smoke Propellants

Aging mechanism is the same

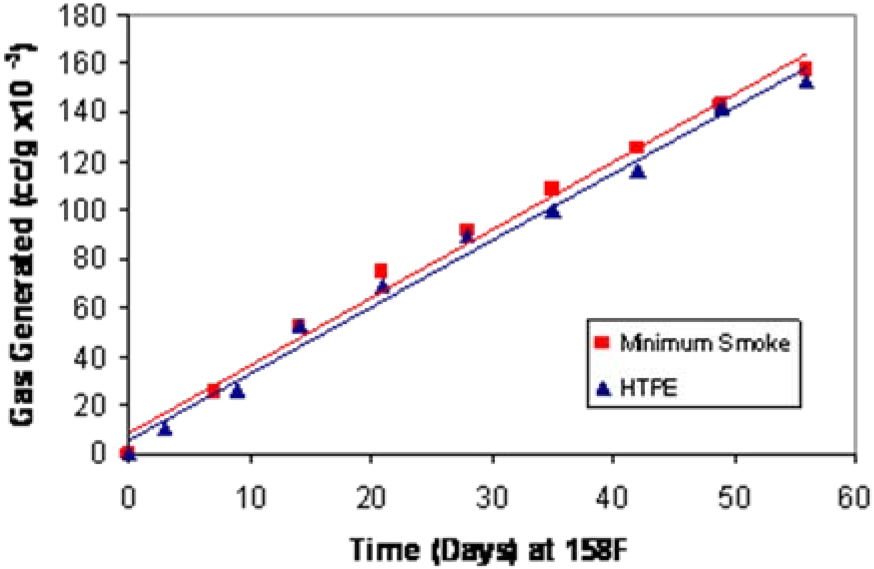
Both have polyurethane binders plasticized with nitrate esters

- BuNENA compared to NG/BTTN

Both stabilized with N-methyl-p-nitroaniline (MNA) and 2-nitrodiphenylamine (NDPA)

Over time the nitrate esters degrade and the stabilizers remove the generated nitrogen oxides to prevent autocatalysis and attack on urethane crosslinks

Effective gas generation and service life is the same for both for HTPE and minimum smoke propellants



Stabilizer Depletion and Service Life

- **Studies have shown that when the MNA stabilizer concentration goes below 0.10% service life (at high temperature) will end due to rapid gas generation and propellant softening for both HTPE and minimum smoke propellants**

- **MNA depletion can be easily measured during propellant aging to measure service life**

- **Based on MNA depletion rate data at various temperatures the activation energy can be calculated and the service life at other temperatures or temperature cycles can be calculated**

Stabilizer Depletion and Service Life

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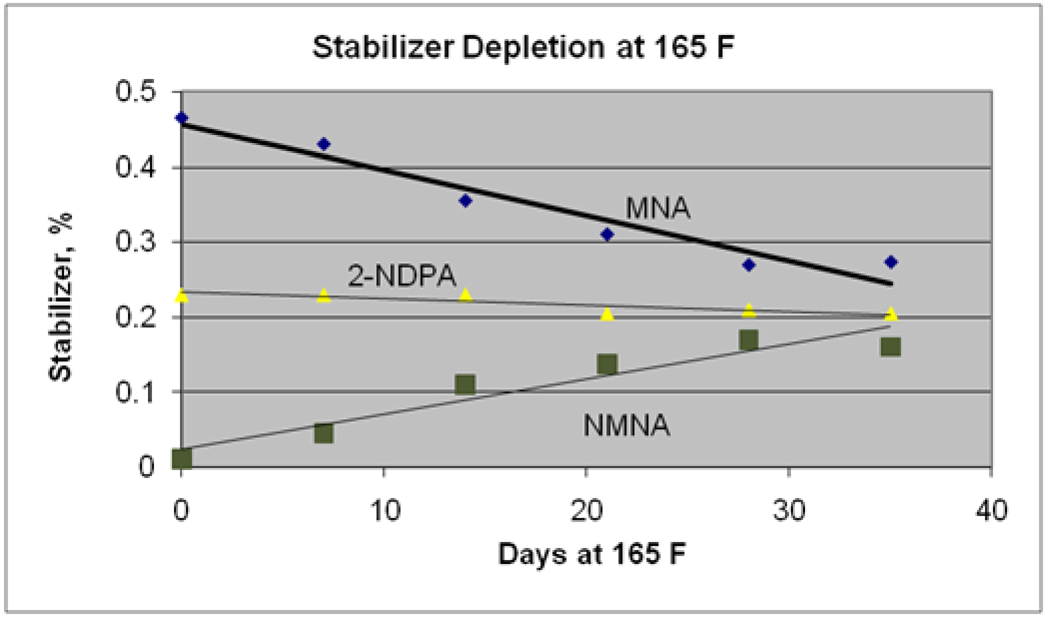
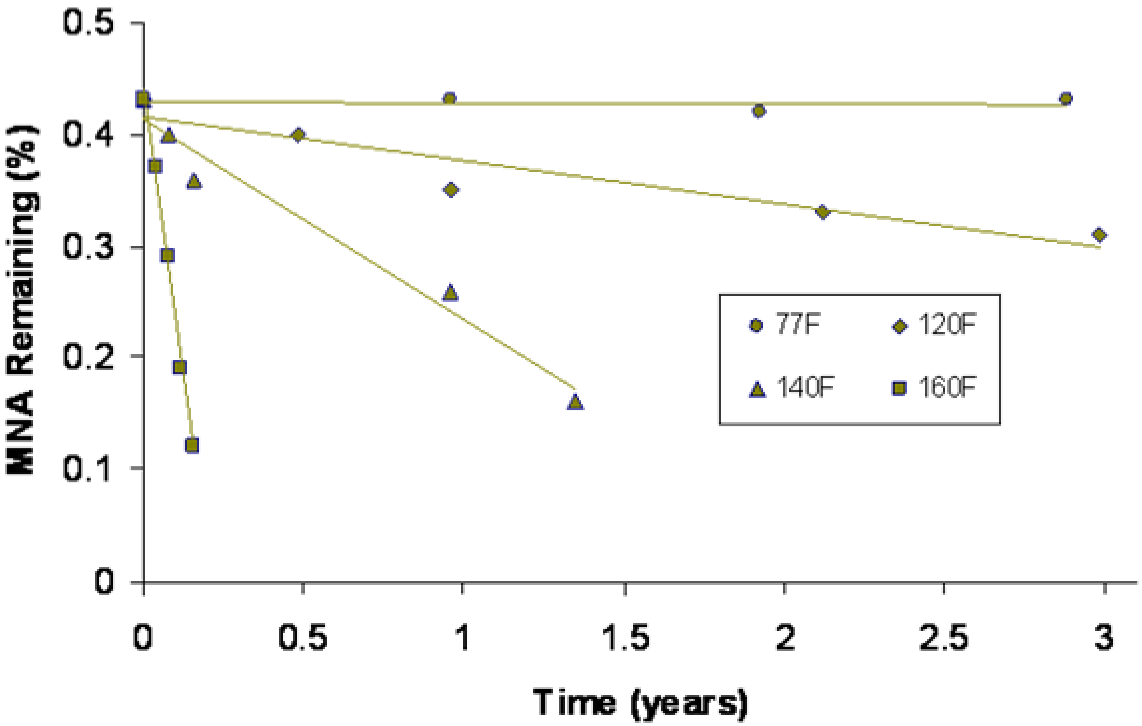
- **In a typical test the propellants are withdrawn from aging periodically and a sample is analyzed for MNA, NDPA and nitroso-MNA (NMNA) the MNA depletion product**
  - **Mechanical properties are often measured at the beginning and end of the aging period**
- **MNA depletes in a linear fashion and is converted to NMNA**
  - **NDPA concentration is fairly constant until the MNA goes below 0.10%**



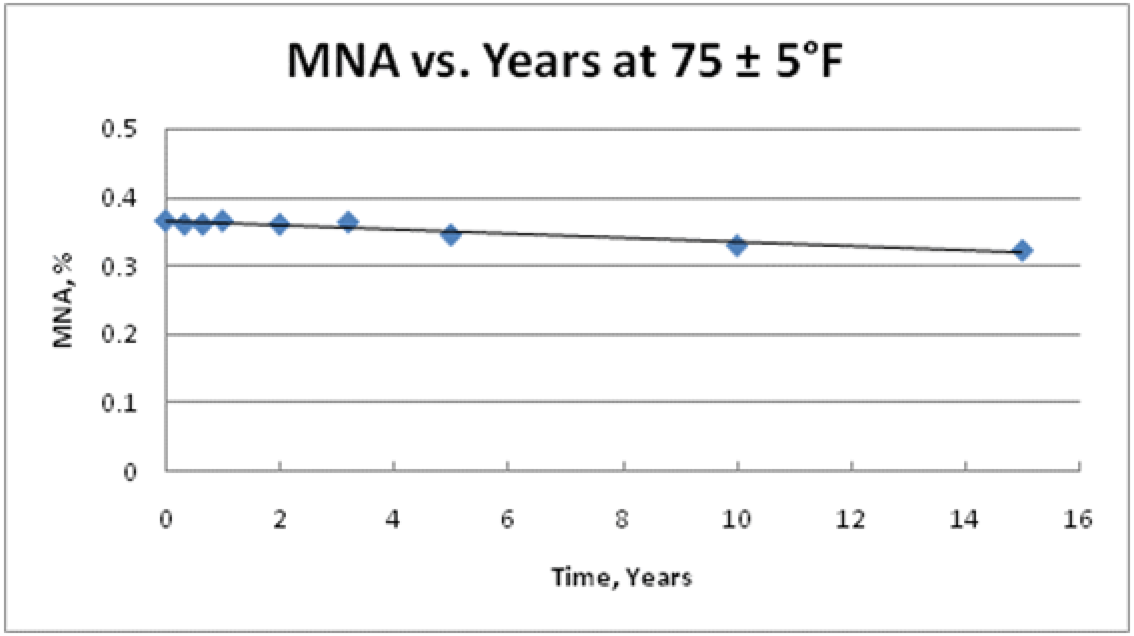
Stabilizer Depletion for Aluminized HTPE

- **MNA depletion measured at four temperatures**
  - **In this study there was no measurable stabilizer depletion in three years at 77°F (25°C)**



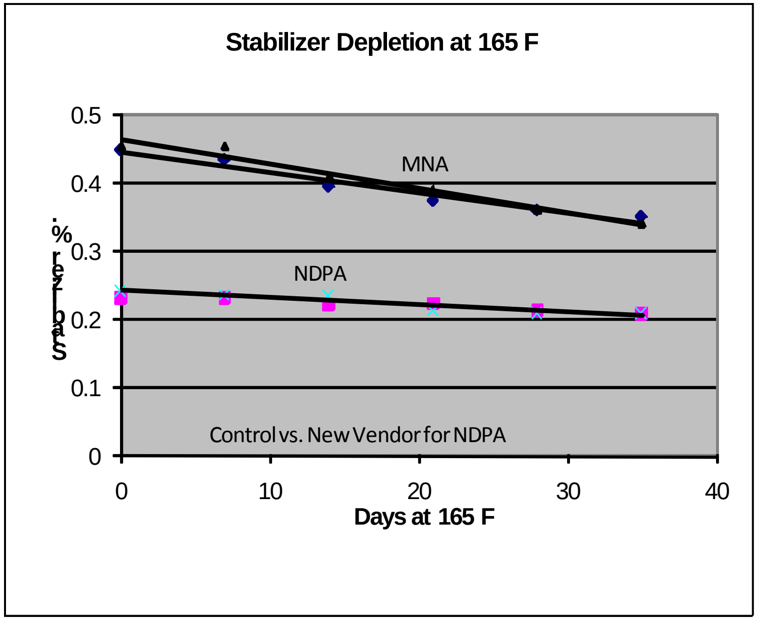
Stabilizer Depletion for Long Term Aging

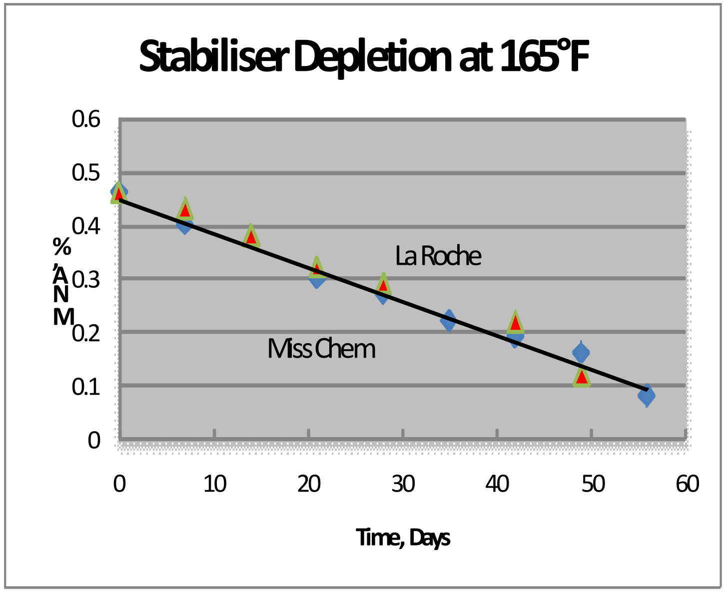
- **In a test of stabilizer depletion for HTPE propellant there was a steady slow decrease in MNA content over fifteen year time period**
  - **Data was averaged from two 50-gallon propellant mixes made in 1993**
  - **Initial MNA content was increased subsequent to these mixes**
- **MNA content is calculated to reach 0.10% in 125 years at 75±5°F (25±3°C)**

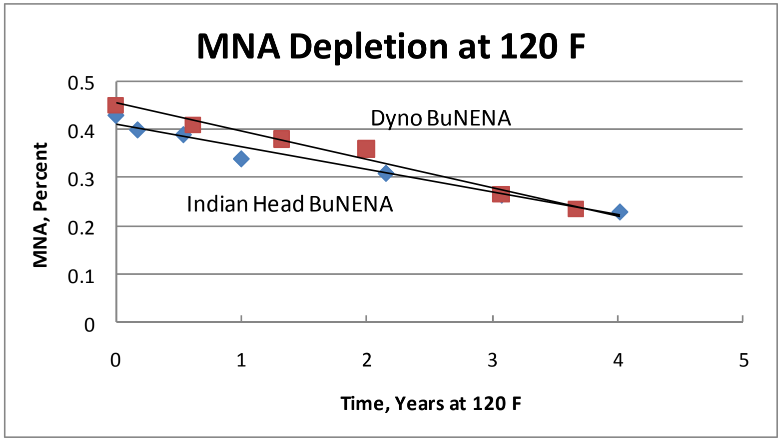


Stabilizer Depletion Used to Evaluate New Ingredient Sources

- **As in many motor production programs new suppliers for ingredients are required from time to time**







Stabilizer Depletion -- HTPE vs. Minimum Smoke Propellants

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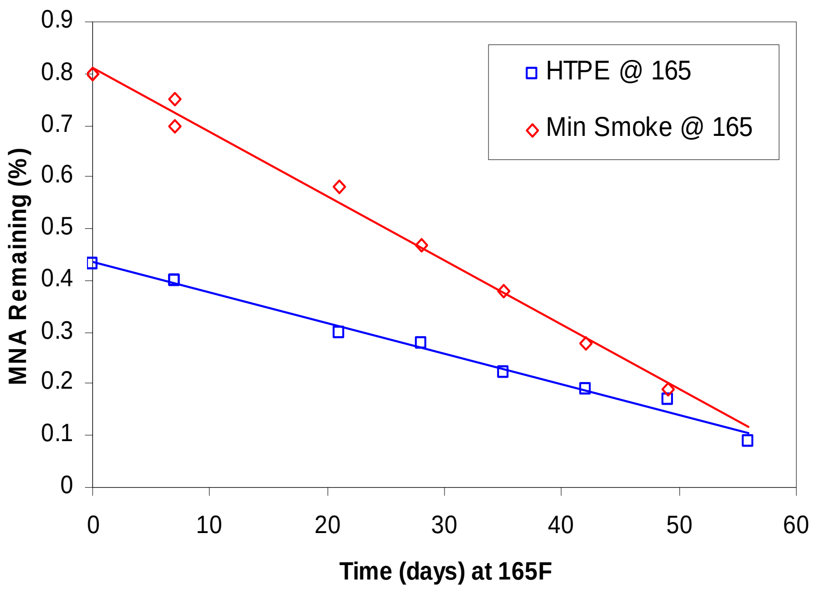
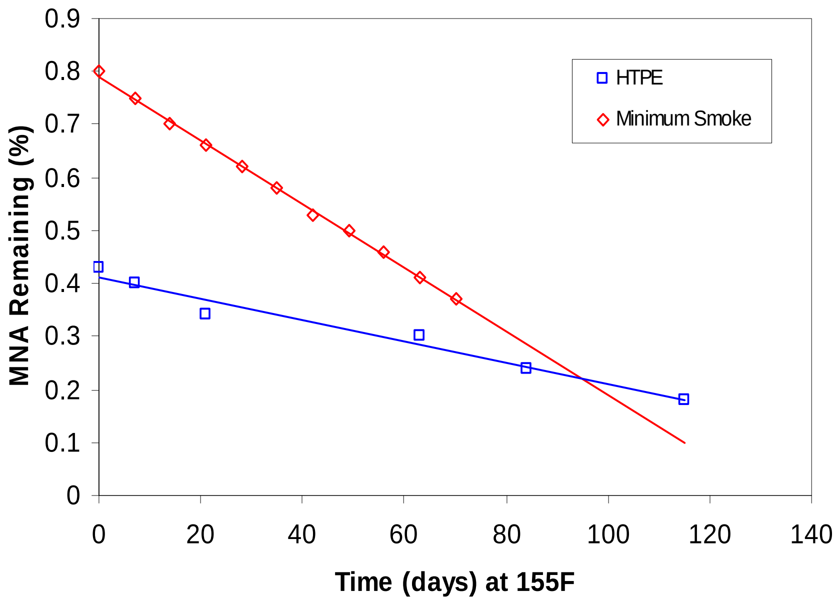
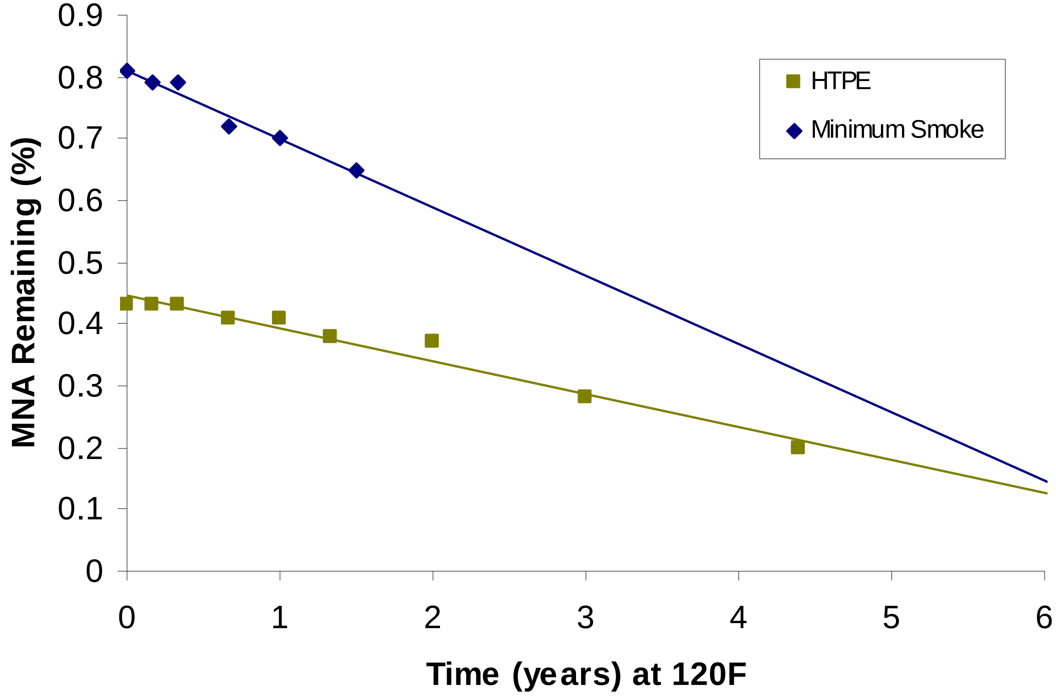
- **HTPE propellants are formulated with about half the initial stabilizer content of minimum smoke propellants**
- **MNA stabilizer depletes at about half the rate in HTPE propellant than it does in minimum smoke TOW and Hellfire propellants**
- **Time to reach 0.1% MNA is about the same for HTPE propellant, therefore service lives based on stabilizer depletion will be the same**
  - Over 40 HTPE mixes tested at 165°F (74°C)





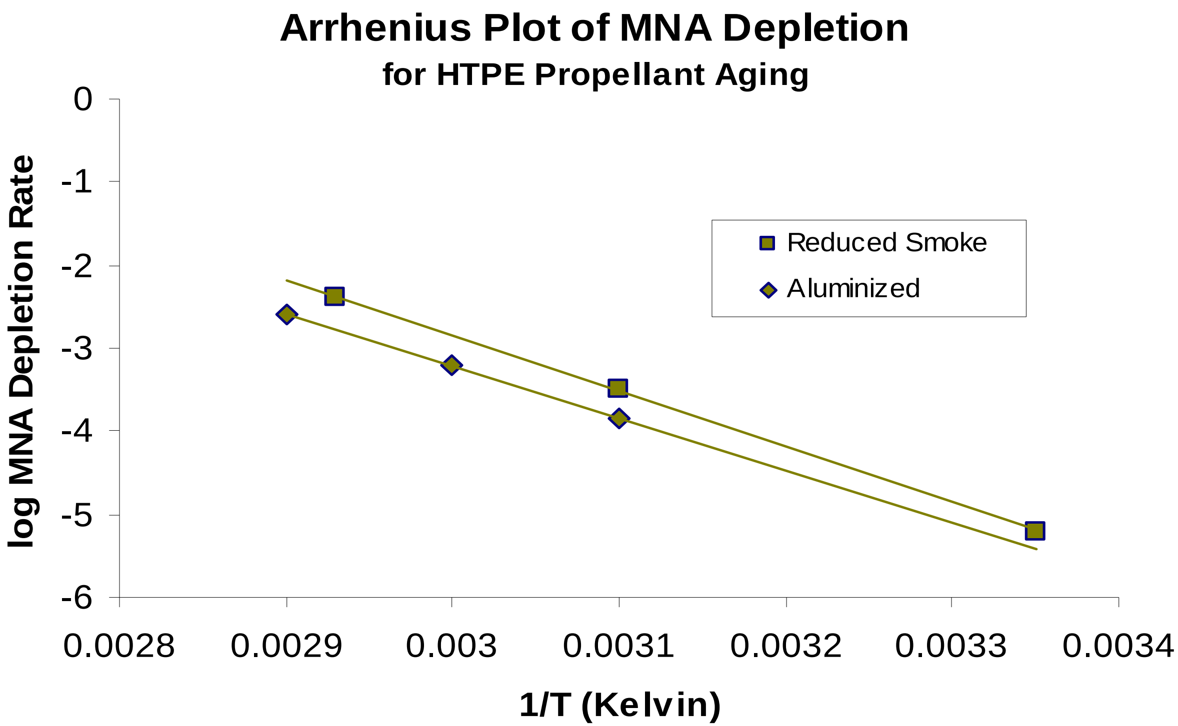
Stabilizer Depletion -- HTPE vs. Minimum Smoke Propellants

- **MNA depletion time to 0.1% is projected to be about six years at 120°F for both HTPE and minimum smoke propellants**
- **Expect to have the same service life based on stabilizer depletion**
- **Minimum smoke propellants in TOW and Hellfire motors have demonstrated acceptable service life in a variety of tactical storage conditions**



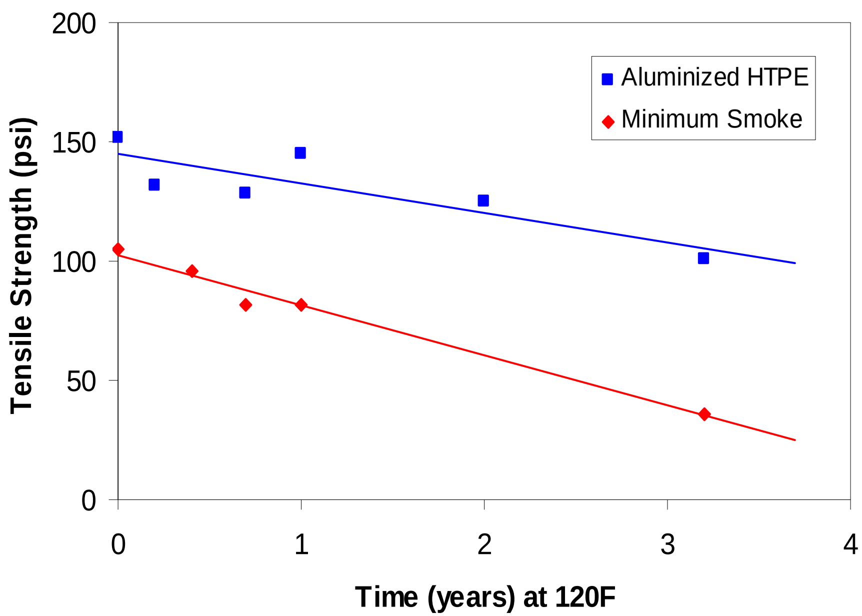
Stabilizer Depletion -- Arrhenius Plot of HTPE Aging Data

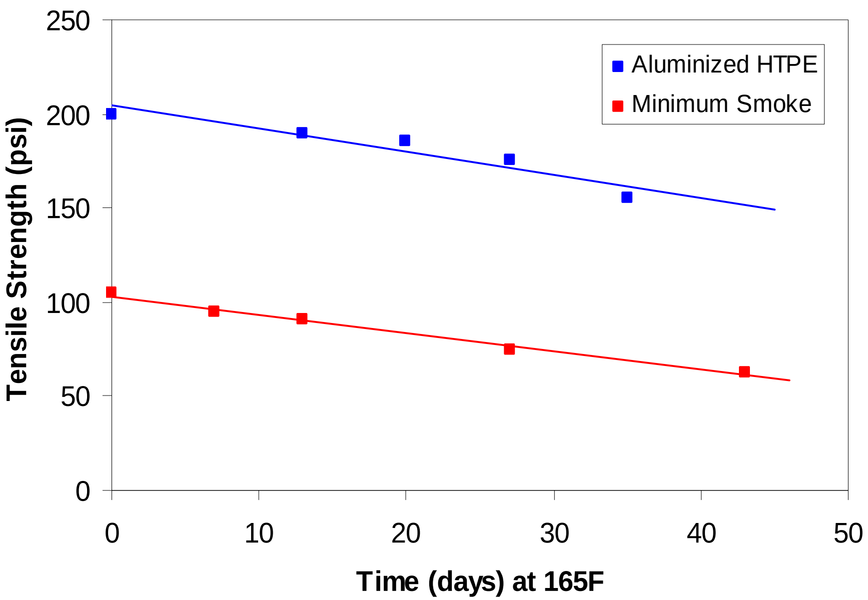
- **Same activation energy range as for minimum smoke propellants**
  - **Ea = 26 to 29 kcal/mole**
- **Can calculate MNA depletion time at any temperature or temperature cycle**



Tensile Strength Aging of HTPE Propellants

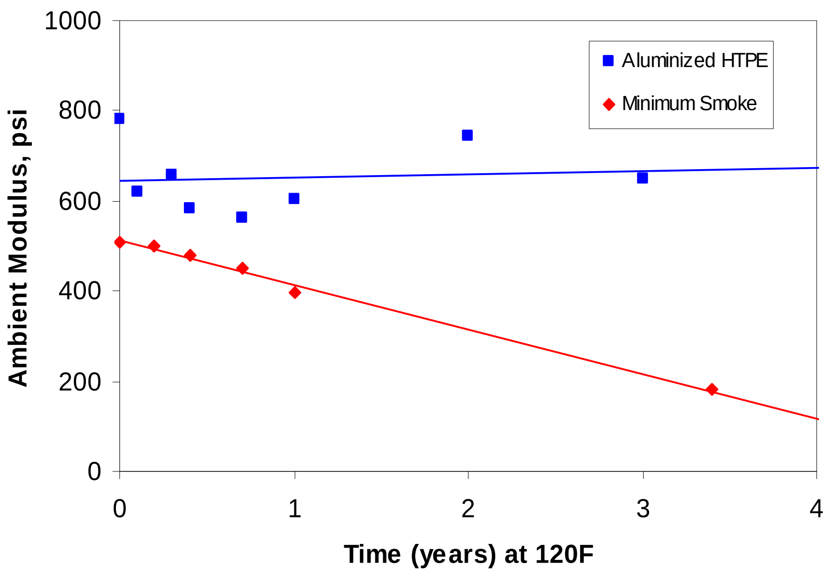
- **Mechanical properties of HTPE propellants are more stable than currently deployed minimum smoke propellants**
  - **During aging tensile strength and modulus decrease and strain increases**
  - **Mechanical property aging has been measured at 77, 120, 155 and 165°F**
- **Tensile strength comparison for propellants aged at 120 and 165°F**

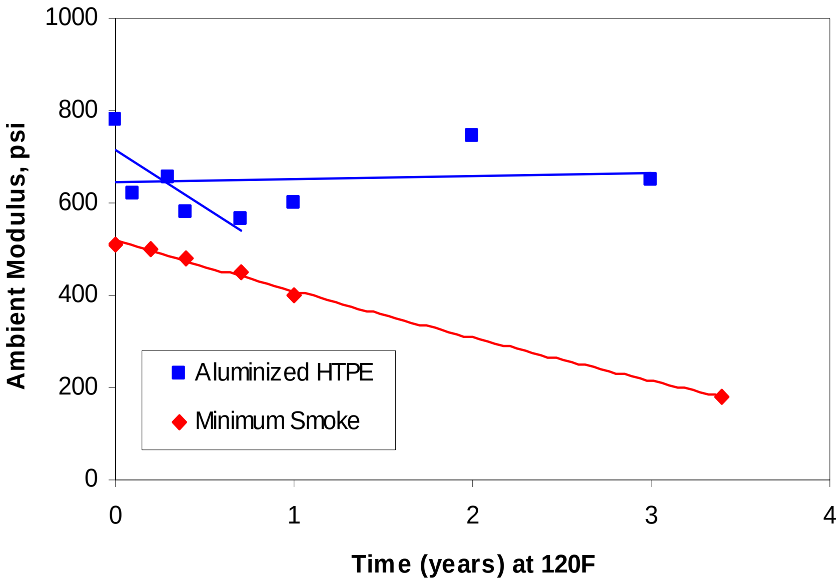




Modulus Aging of HTPE Propellants

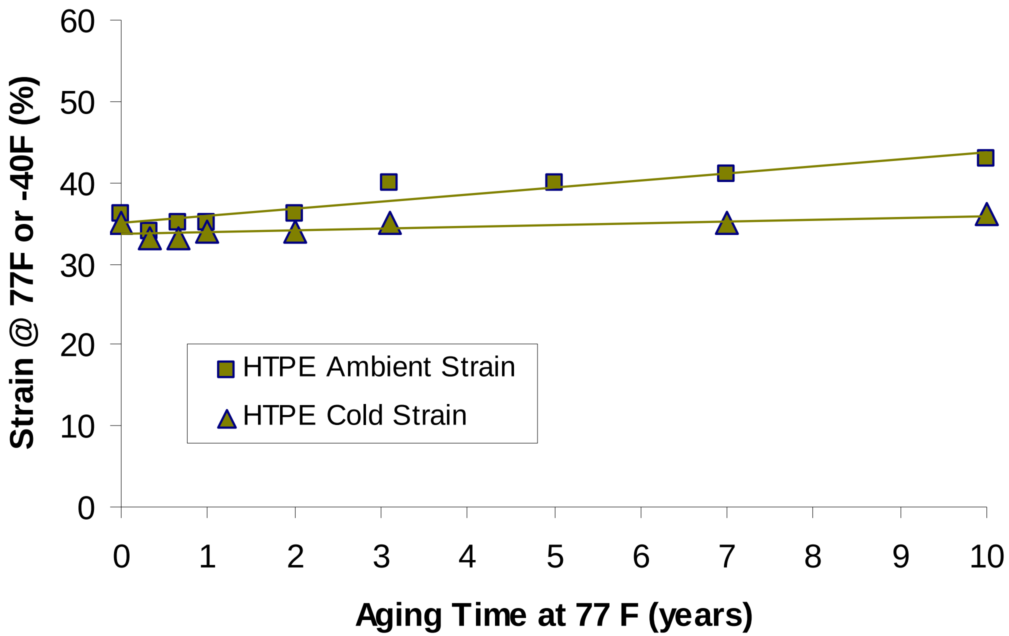
- **Modulus of HTPE propellants are more stable than currently deployed minimum smoke propellants**
  - **Mechanical property aging has been measured at 77, 120, 155 and 165°F**
- **The second chart below shows that extrapolating initial data can sometimes lead to the wrong service life prediction**





Strain Aging of HTPE Propellants

- **Strain capability of HTPE propellants slowly increases with aging time**
  - **Similar behavior to minimum smoke propellants**
- **Ambient and cold (-40°) allowable strains increase slowly during ten-year ambient storage for HTPE propellant**



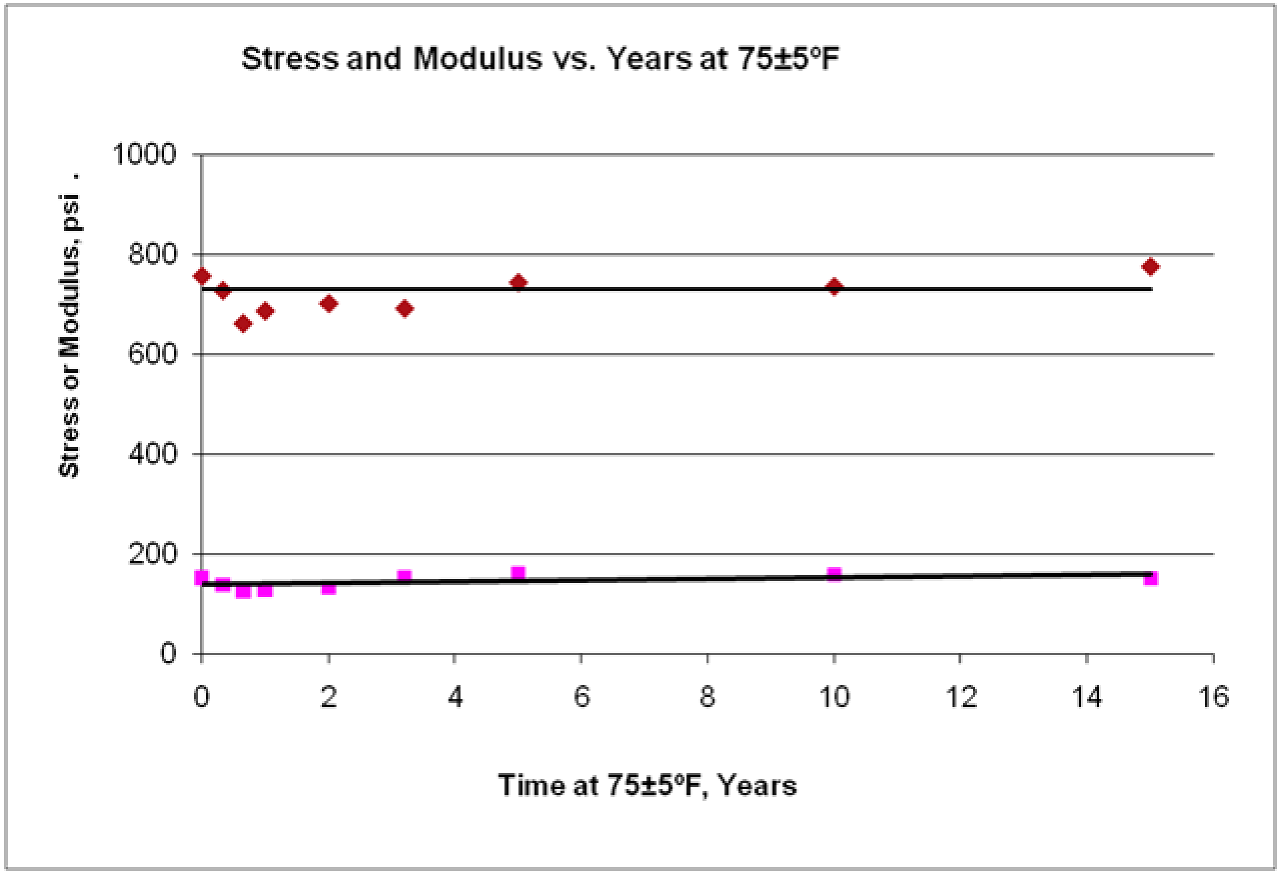
Fifteen-Year Propellant Aging

- Propellants in this study are HTPE formulations manufactured in two 50-gal mixes in 1993
- Storage temperature is 75 ± 5ºF (25 ± 3°C)
- The only changes in properties after fifteen years aging were a small decrease in MNA content
- Stabilizer depletion projects to very long service life

Property	Initial	Five Years	Ten Years	Fifteen Yrs
77ºF Stress, psi	152	161	158	150
Strain, %	36	40	42	34
Modulus, psi	757	744	737	776
-40ºF 0.02 ipm Strain, %	35	35	36	-
MNA, %	0.365	0.345	0.33	0.323
2-NDPA, %	0.24	-	0.24	0.255

Fifteen-Year Propellant Aging

- **Mechanical properties of HTPE propellants are very stable under long-term aging**



Additional Aging Data for HTPE Propellants

- Extensive aging tests have also been performed using case bond samples and dual propellant specimens that demonstrate the long term stability of HTPE propellants

- The activation energy for tensile strength and modulus changes is about 28 kcal/mole, the same value as for stabilizer depletion

- Burning rate is also stable during long term aging

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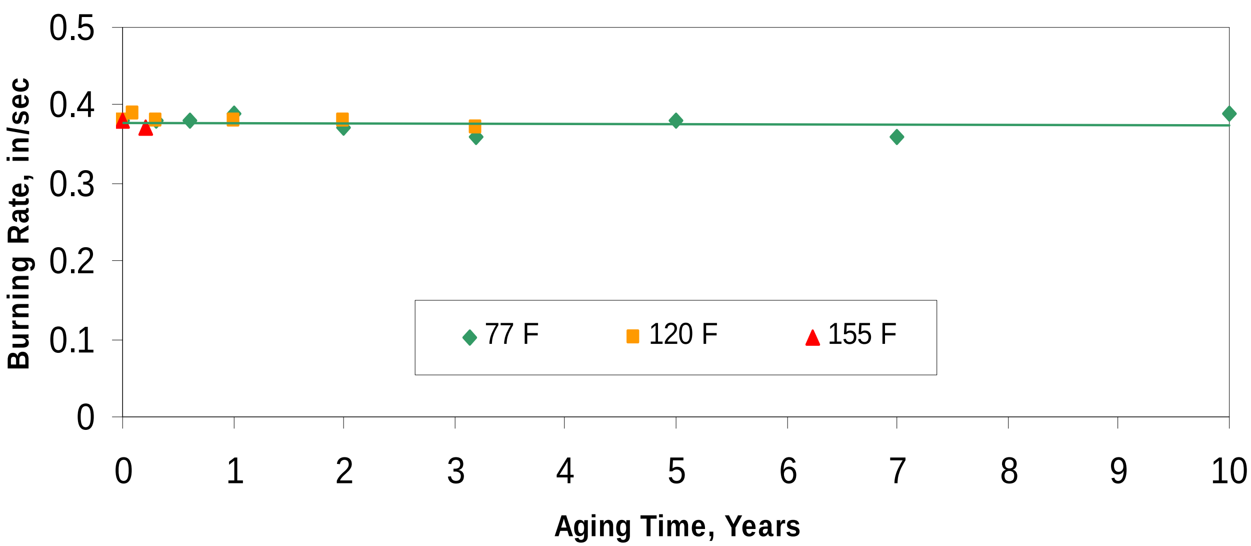

Summary

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- **Aging data was obtained on over 90 different HTPE propellant mixes demonstrating long term service life**
  - **Based on gas generation, stabilizer depletion, mechanical property and burning rate measurements over aging times as long as fifteen years**
- **HTPE propellants are projected to meet tactical motor service life requirements as extreme as those actually experienced by TOW and Hellfire motors now deployed around the world**
- **Word of caution: To obtain long service life ingredients must be selected that are compatible with BuNENA nitrate ester**
  - **For example, many suppliers of commercial ammonium nitrate use anticaking agents or phase stabilizers that accelerate the decomposition of BuNENA**