Nanotechnology for Lubricants to Improve Performance and Reliability of Army Systems

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About Us

• Founded in 1997

• Today, conducting R&D, manufacturing and marketing diverse Advanced Materials products

• Two facilities in New Jersey (15,000 ft² space)

• Products sold under NANOMYTE® trademark
Core Competency

- Nanotechnology expertise
  - Bridge gap between basic and applied science by relating material properties to product performance
  - Design and develop products (nanoparticles, nanocomposites and nanostructured materials)

- In-house capabilities to *prove concept* and *demonstrate prototype* in relevant environment

- Technology based, application driven, customer focused
Nanomaterial Products

Nanomyte® Series for:

- Advanced Protective Coatings
- Energy Storage Materials
- Environmental Nanomaterials
- Nanoparticle Fluids
Application Need

• **Lubricants** used in the Army’s ground and airborne vehicles

• Lubricants with more efficient **heat transfer** can lead to:
  - Reduced erosion of the gears
  - Reduced downtime
  - Reduced maintenance costs
  - Extended operation

• Engineer the lubricant (oil/grease) to enhance heat transfer properties
Challenge

Heat Transfer Correlation for Forced Convection in a Tube

\[ h \propto k^{2/3} \cdot C_p^{1/3} \cdot \rho^{0.8} / \eta^{0.467} \]

- **Maximize Increase in Thermal Conductivity**
- **Minimize Increase in Viscosity**
- **Minimize Decrease in Heat Capacity**
- **Maintain or Improve Lubricity**
Initial Work

• Base Fluid:
  – Valvoline Synpower 75W90 (VV975) Gear Oil

• Additives
  – Commercially available, Micron-Scale Additive: Micro-1
  – NEI-Synthesized, Nanostructured Additive: Nano-1
  – Commercially available, Micron-Scale Additive: Micro-2
  – NEI-Synthesized, Nanostructured Additive: Nano-2
Results:
Comparison of Dispersion Stability Over Time (without agitation)

Nanostructure allows for highly stable dispersions
Results:

Viscosity Measurements at 40°C

- More Newtonian Flow
- Viscosity Reduction
Results:
Comparison of Additive 1 and Additive 2
Thermal Conductivity of Dispersions in Oil at 40°C

![Bar chart showing the thermal conductivity of Base Oil, Nano-1, and Nano-2. Nano-2 has a +11% increase compared to the base oil. Nano-1 has a +3% increase compared to the base oil.](chart-url)
Results:

Effect of Dispersed Solids on Viscosity Index (VI)
ASTM D2270 - Kinematic Viscosity Calculated from Absolute Measurements

- Some reduction in VI for Nano-1
- Significant increase in VI for Nano-2

Potentially Allows for Wider Operating Temperature Range
Scale-up and Independent Standardized Testing:

• **Base Fluid**: Valvoline Synpower VV975
  “Base Oil”

• **Base Fluid + Commercial Nano Additive**: “Commercial” (using recommended amount)

• **Base Fluid + NEI Nano Additive**: “Nano-2”
Results:
Comparison of Oil Additives
Thermal Conductivity of Oil Dispersions at 40°C

Thermal Conductivity (mW/m·K)

Nano-2 | Commercial | Base Oil

145
140
135
130
125
120
Results:
ASTM D2983 Low Temperature Viscosity, -40°C

Results:
ASTM D2270 Viscosity Index

Results:
ASTM D4172 4 Ball Wear Test

Scars form at contact points

Average Wear Scar Diameter (mm)

<table>
<thead>
<tr>
<th></th>
<th>Base Oil</th>
<th>Commercial</th>
<th>Nano-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
<td>0.8</td>
<td>1.2</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Extreme Pressure Testing:
ASTM D2783 4 Ball EP Test
ASTM D3733 Falex EP Test

Example:
Hypoid Gears

Results:
ASTM D2783 4 Ball EP Test
Wear Index and Weld Point

High index indicates reduced friction

Results:
ASTM D3733 Falex EP Test
Load to Failure

ASTM D3233B - Failure Load (lbf)

Load to failure (pin seizes)

Product Development and Demonstration

- Further Optimization of High Conductivity Additives
- Surface Functionalize for Dispersion in Aviation Oils
  - MIL-PRF-23699F Turbine Oil
  - Aviation Gear Oil
- Performance Testing
  - In-House
  - USC Apache Drivetrain Facility
Optimization of Thermal Conductivity

Thermal Conductivity (mW/m·K)

- Base Oil
- 1% Micro-3
- 0.5% Nano-3
- 1% Nano-3

17% increase in thermal conductivity
Optimization of Stability

Thermal Conductivity (mW/m·K) vs Time (hr)

- Nano-5
- Nano-6
- Nano-7
- Nano-8

High Stability
In-House Performance Testing

Oil Thermocouple

Shear Generator

Cool Air ~23°C

Control Nano-2 Cooling Rate (°C/min)

60% Faster Cooling
Simulated Use Conditions
USC Apache Tail Rotor Drivetrain Facility

Intermediate Gear Box (IGB)
Simulated Use Conditions

Gearbox Operated Without Load

Average Gearbox Temperature

Cumulative Vibrational Energy
Simulated Use Conditions

Gearbox Operated WITH Load

Average Gearbox Temperature

Temperature (°F) vs. Time (min)

AGL
Nano-4
Simulated Use Conditions

Gearbox Operated WITH Load

Cumulative Vibrational Energy

Cumulative sum of energies-after load step 3

Cumulative sum of energies-after load step 4
Future Development

Synthesize nanocomposite particles

Characterize nanocomposite particles

Incorporate nanocomposite particles in fully formulated lubricants

Incorporate nanocomposite particles upstream during the lubricant synthesis process

In-house laboratory testing of lubricants

Testing under simulated use conditions

In-House and external used lubricant analysis

QUALIFICATION TESTING

Long-term & field testing
Qualification Testing

- Viscosity Grade, per ASE and ISO
- Viscosity Index, ASTM D2270
- Pour Point, ASTM D97
- Flash Point, ASTM D92
- Oxidation Resistance, ASTM D943, D2272
- Rust Protection, ASTM D665
- Water Separability, ASTM D1401
- Copper Corrosion, ASTM D130
- Foam Test, ASTM D892
- FZG Scuffing, ASTM D5182, DIN 51534
Thank You