PCMO Formulating Advances to Deliver Fuel Economy

DAP Theme: Fuel Economy – How Do We Get There?

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Total Cost of Ownership and Conservation of Resources
Automotive Engine Oil OEM Focus Area for Next Decade

Fuel Economy

Extended Service and Durability
Additives Help Find the Right Balance

Formulating for next-generation categories is a mixture of science and art that requires commitment, creativity, precision and lots of experience.

- Simultaneously meeting requirements, that sometimes conflict, is a formidable challenge.
- Additive formulating technology needs to provide wear, reduced friction, and universal oil capability without sacrificing wear protection and durability.
### Fuel Economy Drives Technology Implementation

<table>
<thead>
<tr>
<th>Operating Environment</th>
<th>Impact on Engine Technology</th>
<th>Impact on Oil Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Cycles NEDC, FTP, WHTC, stop/start</td>
<td>Fuel Economy under transient / transitional conditions</td>
<td>DI and VI Selection + Base Oil Formulating Technologies, oil film control/wear</td>
</tr>
<tr>
<td>Friction Reduction</td>
<td>New materials, surface finishes, coatings</td>
<td>Surface chemistry and additive interactions, surface “wetting” or film formation</td>
</tr>
<tr>
<td>Combustion Optimization</td>
<td>EGR, VVT</td>
<td>LSPI, aeration, corrosion control</td>
</tr>
<tr>
<td>Downsizing</td>
<td>Higher power density, direct injection, turbo-charging</td>
<td>LSPI, Oxidation, high temperature deposit control</td>
</tr>
<tr>
<td>Downspeeding</td>
<td>Narrower operating range, Low speed, high load operation</td>
<td>LSPI, boundary lubrication</td>
</tr>
</tbody>
</table>
Regardless of Vehicle and Engine Technologies
Basic Functions of Additives Remain the Same

- Altering frictional properties of fluids and surfaces
- Preventing wear
- Maintaining surface cleanliness
- Prevent aging and breakdown of oil
- Containing and controlling impact of contaminants in engine oil
- Preventing corrosion
Specific Power Output Has Increased Significantly While Reducing Fuel Consumption

- Significant gains have been made in power density
- Fuel consumption per displacement remained relatively flat
- Increased HP/Displacement paves the way for downsizing

Source: U.S. EPA
Increased Specific Power Output Places Higher Demands on Engine Oil Performance

- From 1980 through 2015, engine displacement remained relatively flat.
- Improved power density was largely used to enhance vehicle performance, not down-size for fuel economy.

Source: U.S. EPA

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Fuel Economy Will Continue To Drive Technology Introductions For The Next Couple of Decades

- Current U.S. targets require 4% improvement per year to meet 2025 objectives
- Engine oil will play the dual role of directly impacting fuel economy and enabling new engine technologies
- Increasing fuel economy requirements are driving lower viscosity oils into the marketplace

Source: The International Council on Clean Transportation

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Engine Lubricant is a Cost Effective Method to Improve Fuel Economy

Data from U.S. Department of Transportation Report RIN 2127-AK29

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Driveline Technologies are Changing Rapidly
Engine Oil Often Plays an Enabling Role

Source: U.S. EPA
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Implementation of Fuel Savings Technologies
Light Duty Vehicles – U.S. Market

Turbo Enabler: Oxidation Control

Source: U.S. EPA
Implementation of Fuel Savings Technologies
Light Duty Vehicles – U.S. Market

VVT/Cylinder Deactivation Enabler: Oil Aeration Control

Source: U.S. EPA
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GDI Enabler: Soot Dispersancy

Source: U.S. EPA
Implementation of Fuel Savings Technologies
Light Duty Vehicles – U.S. Market

GDI/Turbo/Downspeeding Enabler: LSPI, Oxidation, Soot

Source: U.S. EPA
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Combination of New Technologies Places New Demands on Engine Oil

- Low Speed Pre-ignition (LSPI) has become more important to OEMs as turbocharged, direct injected engines with down speeding become more prevalent
  - LSPI prevents engines from operating at optimal conditions
- Potential to break engine parts, cause audible noise to end users

Turbo-downsized gasoline direct injection engines are rapidly being introduced in many markets and placed new demands on PCMO formulations as an enabler (LSPI, chain wear, etc.)

Source: EPA, SAE 2013-01-2569
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New Technology Leads to New Requirements
Low Speed Pre-Ignition (LSPI) Enters the Picture

- LSPI results in formation of a new flame front (deflagration mode) due to an unknown initiator that leads to knock
  - Unlike standard knock, the initiator can’t be described with bulk gas properties
- Has actually been found to occur pre-ignition or post-ignition (similar to surface ignition)
Engine Oil Formulation Impact on LSPI

- Engine oil formulations will impact the frequency of LSPI events based on initial work performed by Oronite.
- Various lubricant components that play a role in LSPI:
  - Ca, Fe, Cu promote LSPI
  - MoDTC, ZnDTP suppress LSPI
  - Oil degradation promotes LSPI
  - Impact from the base stocks were observed, with no correlation to NOACK
- In combination with engine oil, fuel composition and hardware design are other possible factors that contribute to the LSPI phenomena.
The PCMO Formulating Challenge
The puzzle becomes more challenging as we add more pieces

- Oxidation
- Deposit Control
- Wear Control
- Sludge Control
- Bearing Corrosion
- Used Oil Low Temp Viscosity
- Rust Control
- Seal Protection
- E85 Compatibility
- Catalyst Protection
- Turbo Protection
- LSPI
- Chain Wear
- Fuel Economy
- What's Next?
- What's Next?
### GM dexos1™:2015
First Global OEM Specification Addressing New Technologies
LSPI AND TURBOCHARGER PERFORMANCE TEST

<table>
<thead>
<tr>
<th>Requirements</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation Oil Release</td>
<td>IIIG, OP1</td>
<td>IIIG/ *GMOD, **OP2</td>
</tr>
<tr>
<td>Turbocharger</td>
<td>-</td>
<td>NEW TEST</td>
</tr>
<tr>
<td>Aeration</td>
<td>MEC024</td>
<td>NEW TEST</td>
</tr>
<tr>
<td>LSPI</td>
<td>-</td>
<td>NEW TEST</td>
</tr>
<tr>
<td>Wear</td>
<td>RNT, TU3MS</td>
<td>RNT, TU3MS</td>
</tr>
<tr>
<td>Fuel Economy</td>
<td>VID</td>
<td>VID/E, GMVFE (NEW TEST)</td>
</tr>
<tr>
<td>Cold Flow</td>
<td>IIIGA</td>
<td>IIIGA / *GMODA</td>
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<tr>
<td>Phos Retention</td>
<td>-</td>
<td>IIIGB / *GMODDB</td>
</tr>
<tr>
<td>Bearing Corrosion</td>
<td>VIII</td>
<td>VIII</td>
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*pending precision matrix completion and GM approval
**pending test development

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# Future Impacts on Additive Formulation

## Total Cost of Ownership (TCO)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Fuel Economy</th>
<th>Extended Service/Durability</th>
<th>Sustainability</th>
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</thead>
<tbody>
<tr>
<td>Ultra Low Viscosity Oils</td>
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<tr>
<td>Surface Treatments for Reduced Friction and Wear</td>
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<tr>
<td>Turbo-Downsizing</td>
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<tr>
<td>Advanced Thermal Management</td>
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<td>Reduced Maintenance and Long Drains</td>
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<td>Renewable Fuels</td>
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## Additives Impacted

- Supplemental Wear Inhibitors
- New Friction Modifiers
- New Deposit Control Additives
- New Nitration Inhibitors
- TBN Retention Additives
- New Oxidation Inhibitors

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Engine Oil Must Meet The Needs of Multiple Generations of Vehicles

- The quality of vehicles and engine oils has improved significantly which allows vehicles to stay in service longer. Engine oils must be formulated to meet new vehicle requirements and existing vehicle requirements.

- 2014 total light vehicle population 252 million (up 3.7 MM or 1.5% from 2013)
- Median age vehicle is 11.4 years old and has more than 130,000 miles

Source: R. L. Polk

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Customers Also Influence the Market
Fuel Economy Performance Top of List, But In Decline

Q: Which performance feature in the next generation of engine oil, GF-6, would be most important to your customers?

- Improved fuel economy
- Increased drain capability
- Other*
- Sludge control
- Performance in smaller displacement engines
- Performance in hybrid applications
- Protection of catalyst and emissions system sensors
- Turbo performance

Source: Oronite Annual Fast Lube Survey

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PCMO Formulating Requirements
Go Beyond Performance Features

- Product Economics ($)
- Enable & Maximize Fuel Economy
- Ensure Engine Protection
- Deliver Engine Cleanliness
- Minimize Supply Chain Complexity
Summary

- Total cost of ownership, including fuel economy and extended drain are the focus area for engine oil development over the next decade
- Demands for increased vehicle fuel economy are leading to new driveline technologies entering the market
  - Engine oil plays the dual role of directly increasing fuel economy through the use of lower viscosity oils while at the same time enabling new hardware technologies to be introduced
  - The move towards lower viscosity and higher quality engine oils will continue and accelerate
- Technologies such as turbo charging, Gasoline Direct Injection, and engine downsizing are placing greater demands on engine oil formulations
- Engine life and durability cannot be sacrificed for fuel economy gains
  - Life expectancy of engines and vehicles is increasing due to improved hardware quality as well as better fuels and lubricants