Passenger car engine oil
Introduction and outline

- The components of a PCEO additive package
- API SN-PLUS and ILSAC GF-6 specifications
- The PCEO market and future trends
Overarching formulation considerations

- ACC Code of Practice, ATC Code of Practice, API EOLCS guidelines, and ATIEL guideline
- Desired performance level or specifications
- Viscosity grade coverage
- Customer / oil company requirements
- OEM requirements including factory fill or service fill applications
- Base stock availability and quality
- Component and viscosity modifier (VM) technology
What goes into a finished PCEO?

- Base stock, 72-89%(m)
- Additive package, 5-12%(m)
- Viscosity modifier, 5-15%(m)
- Pour point depressant, <1%(m)
### What goes into a PCEO additive package?

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Typical type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersant</td>
<td>Suspension of soot, sludge, and deposit precursors</td>
<td>PIBSA/PAM</td>
</tr>
<tr>
<td>Detergents</td>
<td>Prevention of rust, corrosion, and deposit adhesion</td>
<td>calcium or magnesium based sulphonates, phenates, and salicylates</td>
</tr>
<tr>
<td>Antioxidants</td>
<td>Prevention of oxidation via radical traps and peroxide decomposition</td>
<td>ZDDP, diphenylamine, hindered phenols, metal and/or sulfur-based</td>
</tr>
<tr>
<td>Anti-wear agents</td>
<td>Prevention of surface microwelding and tearing</td>
<td>ZDDP</td>
</tr>
<tr>
<td>Friction modifiers</td>
<td>Reduction of boundary layer friction</td>
<td>short-chain organic acids, ‘solid’ lubricants</td>
</tr>
<tr>
<td>Anti-foamant</td>
<td>Reduction in foaming tendency and stability</td>
<td>polydimethylsiloxane</td>
</tr>
</tbody>
</table>
PCEO categories: past, present, future
ILSAC GF-6

ILSAC GF-6 is driven by a combination of regulatory and/or performance needs

- Fuel economy improvement
- Low Speed Pre-Ignition (LSPI) protection
- Improved deposits protection
- Improved cam chain wear performance
- Replacement of old tests
API and ILSAC gasoline specifications

**API SN/ILSAC GF-5**
- Sequence VID
- Sequence VIII
- Sequence VG
- Sequence IVA
- Sequence IIIG
- Sequence IIIGA
- P & S content
- TEOST MHT
- Ball Rust Test
- NOACK + VGC
- EOWT + EOFT
- Foam + HTFoam
- Miscibility

**API SN Plus**
- Sequence VIE/F
- Sequence VIII
- Sequence VH
- Sequence IVB
- Sequence IIIH
- Sequence IIIHA
- Sequence X
- Sequence IX
- TEOST 33C
- E85 Emulsion

**ILSAC GF-6A/B**
- P & S content
- Ball Rust Test
- NOACK + VGC
- EOFT + EOWT
- Foam + HTFoam
- E85 Emulsion
- Miscibility
- Elastomers

Performance you can rely on.

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## API SP and ILSAC GF-6 engine tests and some have replacements

<table>
<thead>
<tr>
<th>Test</th>
<th>Parameter</th>
<th>Engine description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence IIIH</td>
<td>Oxidation and deposits control</td>
<td>2012 FCA 3.6L PFI</td>
</tr>
<tr>
<td>Sequence IIIIHA</td>
<td>Aged oil viscosity</td>
<td>2012 FCA 3.6L PFI Bench</td>
</tr>
<tr>
<td>Sequence IIIHB*</td>
<td>Phosphorous retention</td>
<td>2012 FCA 3.6L PFI</td>
</tr>
<tr>
<td>Sequence IVB</td>
<td>Wear control</td>
<td>2010 Toyota 1.5L PFI</td>
</tr>
<tr>
<td>Sequence VH</td>
<td>Sludge and varnish control</td>
<td>2013 Ford 4.6L PFI</td>
</tr>
<tr>
<td>Sequence VIII</td>
<td>Bearing corrosion resistance and shear stability</td>
<td>CLR Test 0.7L</td>
</tr>
<tr>
<td>Sequence VIE OR Sequence VIF*</td>
<td>Fuel economy</td>
<td>2012 GM 3.6L PFI</td>
</tr>
<tr>
<td>Sequence IX</td>
<td>Low Speed Pre-Ignition protection</td>
<td>2016 Ford 2.0L GDI</td>
</tr>
<tr>
<td>Sequence X</td>
<td>Cam chain wear protection</td>
<td>2016 Ford 2.0L GDI</td>
</tr>
</tbody>
</table>

*Sequence VIF only required for GF-6B (0W-16)
Engine Tests
Sequence IIIH

Evaluates viscosity increase, piston deposits, and valve train wear during high temperature conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Seq. IIIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>KV40 increase</td>
<td>[%]</td>
<td>≤ 150</td>
</tr>
<tr>
<td>Avg. weighted piston deposits</td>
<td>[merits]</td>
<td>≥ 3.7</td>
</tr>
<tr>
<td>Avg. cam + lifter wear</td>
<td>[µm]</td>
<td>-</td>
</tr>
<tr>
<td>Hot stuck rings</td>
<td>[#]</td>
<td>= 0</td>
</tr>
</tbody>
</table>

PASS

FAIL
Sequence IIIHA (and ROBO)

- Evaluates the low temperature performance of used oil
- Seq. IIIHA utilizes used oil previously evaluated in the Seq. IIIH
- ROBO (Romaszewski Oil Bench Oxidation) intended to simulate oxidation of fresh oil in the Seq. IIIH on the bench scale to improve efficiency in oil qualification
  - Oil oxidized with NO$_2$ and air for 40h at 170°C in the presence of iron catalyst
- Both Seq. IIIHA and ROBO evaluated against the same criteria:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>GF-6 Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRV apparent viscosity at EOT</td>
<td>[cP]</td>
<td>≤ 60,000 (at original or next highest viscosity grade)</td>
</tr>
<tr>
<td>MRV yield stress at EOT</td>
<td>[Pa]</td>
<td>&lt; 35</td>
</tr>
</tbody>
</table>
Sequence IVB

- Evaluates a lubricant’s performance in resisting valve train wear and control of iron concentration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>GF-6 Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Intake Lifter Volume Loss</td>
<td>[µm]</td>
<td>≤ 2.5</td>
</tr>
<tr>
<td>Fe Content at EOT</td>
<td>Ppm</td>
<td>≤ 400</td>
</tr>
</tbody>
</table>

Camshaft Lobe from Toyota 2NR-FE Engine Imaged using 3D Profilometry
Sequence VIII

- Evaluates a lubricant’s performance in resisting copper-, lead-, or tin-bearing corrosion and measures shear stability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>GF-6 limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing weight loss</td>
<td>[mg]</td>
<td>≤ 26</td>
</tr>
<tr>
<td>Shear stability</td>
<td></td>
<td>= stay in grade</td>
</tr>
</tbody>
</table>

PASS

FAIL
**Sequence VH**

- Evaluates a lubricant's ability to prevent sludge and varnish formation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>GF-6 limit Seq. VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine sludge, average</td>
<td>[merits]</td>
<td>≥ 7.6</td>
</tr>
<tr>
<td>Rocker cover sludge, average</td>
<td>[merits]</td>
<td>≥ 7.7</td>
</tr>
<tr>
<td>Engine varnish, average</td>
<td>[merits]</td>
<td>≥ 8.6</td>
</tr>
<tr>
<td>Piston skirt varnish</td>
<td>[merits]</td>
<td>≥ 7.6</td>
</tr>
<tr>
<td>Oil screen sludge</td>
<td>[%]</td>
<td>Report</td>
</tr>
<tr>
<td>Hot stuck compression rings</td>
<td>[#]</td>
<td>= 0</td>
</tr>
<tr>
<td>Cold stuck rings</td>
<td>[#]</td>
<td>Report</td>
</tr>
<tr>
<td>Oil screen clogging</td>
<td>[%]</td>
<td>Report</td>
</tr>
<tr>
<td>Oil screen debris</td>
<td>[%]</td>
<td>Report</td>
</tr>
</tbody>
</table>
**Sequence VIE/VIF**

- Evaluates the effect of engine oil on the fuel economy of passenger cars and light-duty trucks
- Seq VIF run only for 0W-16 viscosity grade with different procedure for Seq VIE

<table>
<thead>
<tr>
<th>SAE Grade</th>
<th>FEI$_2$ Limit [%] Seq. VIE</th>
<th>FEI$_{SUM}$ Limit [%] Seq. VIE</th>
<th>FEI$_2$ Limit [%] Seq. VIE</th>
<th>FEI$_{SUM}$ Limit [%] Seq. VIE</th>
</tr>
</thead>
<tbody>
<tr>
<td>xW-20</td>
<td>≥ 1.5</td>
<td>≥ 3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xW-30</td>
<td>≥ 1.2</td>
<td>≥ 2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10W-30</td>
<td>≥ 1.0</td>
<td>≥ 2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0W-16</td>
<td></td>
<td></td>
<td>≥ 1.9</td>
<td>≥ 4.1</td>
</tr>
</tbody>
</table>
Sequence IX

- Fired engine dynamometer lubricant test which evaluates the ability of a test lubricant to reduce pre-ignition events
- Test sequence (each 175000 cycles) repeated for 4 test iterations
- LSPI events are defined as outliers of peak pressure (PP) and crank angle location of 2% mass fraction burned (MBF02) data.
- Limit on total number of LSPI events across all 4 cylinders averaged over 4 iterations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>GF-6 Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average total number of LSPI events</td>
<td>#</td>
<td>≤ 5</td>
</tr>
</tbody>
</table>
Sequence X

- Sequence X Ford Chain Wear test designed to induce wear on timing chain
- Elongation occurs over time, which can lead to potential misfires and loss of power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit(s)</th>
<th>SN PLUS Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chain stretch</td>
<td>%</td>
<td>≤ 0.085</td>
</tr>
</tbody>
</table>
The PCEO market and future trends
NA viscosity grade trends

- US PCMO lubricant demand for 2018 was estimated around 545 MM gal.
  - Up ~1% from 2017, modest increase due to increased disposable income
  - Significant sales from collective independent brands

- Viscosity grades are changing…
  - SAE 5W-30 remains the dominant grade (40%)
  - Lower viscosities continue to grow
  - Significant growth for 0W-20 seen. Only 10% of the market in 2016, expected closer to 20% by YE 2018
  - SAE 0W-16 continues to be a very niche grade but generates interest
  - More Grp III players in the market in 2018, creating significant qualification work
NA market segmentation

- Conventional ILSAC GF-5 oil is the majority of the market
  - Roll to GF-6 expected to be relatively swift
- Conventional API SN/ILSAC GF-5 included synthetic blend volumes
- Mid Tier includes mainline synthetics, dexos 1, 0W-20 ‘s
  - dexos1 increasingly being commoditized
- Top Tier Includes EU PCMO needs

Market action/reaction concentrated in Mid Tier and Branded Top Tier
- Niche vis grade coverage
- Non-standard claim sets
- Extended drain claims

*Infineum estimate
US OEMs Continue to Drive Oil Performance Forward

- API SN Plus has brought LSPI prevention to the general market
- Some interim OEM specifications have also advanced oil quality ahead of GF-6
- The ILSAC GF-6 specification development targets these performance improvements valued by API and OEMs
General Motors and dexos™

- GM created harmonized specifications to improve efficiency and cost while ensuring consistent quality among suppliers
  - dexos1™ for gasoline engines
  - dexos2™ for diesel engines
- Current dexos1™ includes elements of ILSAC GF-5 (more stringent) and ACEA A in addition to GM/OPEL engine tests
- New dexos1TM generation 3 specification (released in May 2020) will include elements of ILSAC GF-6, as well as two new GM engine tests for transient SPI and Fuel Economy
- GM licenses use of dexos™ trademark separately from the API Service Symbol (‘donut’) and Certification Mark (‘starburst’), and the marketer incurs an annual licensing and royalty fee based on their market share
- dexos1™ program costs about 3-4x an ILSAC GF-5 approval
- Mandatory use of dexos1™:2015 was August 31, 2017
  - To include Low Speed Pre-Ignition (LSPI) protection
  - New dexos1™ Gen 2 trademark
Relative PCMO Spec Performance Comparison

- The API SN PLUS improves upon ILSAC GF-5 solely by LSPI.
- ILSAC GF-6 raises the bar in most every dimension over API SN PLUS.
- dexos1 gen2 is well aligned with ILSAC GF-6 today but does provide additional performance in some areas due to additional tests and limits.
- dexos1 gen3 may help create more of a gap from GF-6 in yet undetermined area.

- SN-PLUS-RC
- GF-6
- dexos1
- dexos1gen2

- LSPI
- FE
- Deposits
- Aeration
- Wear
- Oxidation
- Sludge
- Volatility
Summary

• PCEO formulation requires careful component and base stock selection to achieve balanced performance in combination engine and bench tests defined by a specification

• The NA market continues to experience segmentation due to diverging OEM needs, engine platforms, and consumer preferences

• ILSAC GF-6 will deliver improved fuel economy and more robust engine protection, similar to its predecessors → still a very competitive market segment
Appendix
# Detergents

## Background

Many configurations available including:
- Salicylates, phenates, and sulphonates
- Neutral and highly overbased
- Magnesium and/or calcium

## Formulation considerations

1. Mixture of detergents generally used to provide an balance of attributes
2. Neutral provide detergency for piston cleanliness while overbased provide a source of alkalinity reserve
3. Sulfonates more effective at lower temperature (piston skirt) while phenates more effective at higher temperature (piston crown)
4. Salicylates provide detergency and antioxidant protection, and their low sulfur content enables greater flexibility in restricted formulations
5. Metal variety can affect wear performance
6. Source of ash, a restricted parameter in some applications
# Dispersants

## Background

Many configurations available including:
- High and low molecular weight
- Chloro or thermal
- Borated or non-borated

## Formulation considerations

1. Concentration and type chosen to provide:
   - Sludge and filter plugging control
   - Piston and engine cleanliness
   - Control of soot-induced oil thickening
2. Contributes significantly to additive package and finished oil viscosity, so high treat rates can be detrimental to fuel economy performance
3. Detrimental to CCS viscosity
4. Chloro-dispersant contains residual chlorine, a restricted parameter in some applications
5. May be detrimental to compatibility with certain elastomers
6. Borated dispersants are beneficial in wear and elastomer compatibility, at the expense of sludge control efficiency
# ZDDP

## Background

Many configurations available including:

- High or low molecular weight
- Primary or secondary

## Formulation considerations

1. Provide dual-functionality as both an antioxidant and antiwear component
2. Lower molecular weight provides better wear protection while higher molecular weight provides better thermal stability
3. Secondary provides better wear protection while primary provides better thermal stability
4. Source of ash, a restricted parameter in some applications
5. Contribute phosphorous, a controlled parameter for emissions system protection
6. Highly efficient and cost-effective
## Antioxidants and Friction Modifiers

### Antioxidants

<table>
<thead>
<tr>
<th><strong>Background</strong></th>
<th>Several options available beyond ZDDP including:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Aminic and phenolic</td>
</tr>
<tr>
<td></td>
<td>• Metal – and/or sulfur-based</td>
</tr>
</tbody>
</table>

| **Formulation considerations** | 1. Response of oil to oxidation varies significantly by engine test, so a combination of antioxidants typically used to achieve performance |

### Friction Modifiers

<table>
<thead>
<tr>
<th><strong>Background</strong></th>
<th>Several options available including:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Organic</td>
</tr>
<tr>
<td></td>
<td>• Inorganic</td>
</tr>
</tbody>
</table>

| **Formulation considerations** | 1. Some are highly surface active and can detrimentally impact wear performance |
|                                | 2. Organic FMs may cause stability issues in the additive package or finished oil |
# Viscosity Modifiers

## Background

Many options available including:
- OCP, PMA, styrene/isoprene copolymer
- Functionalized (dispersant) or non-functionalized

## Formulation considerations

1. Exhibit different degrees of temporary and permanent viscosity loss in high-shear operating conditions
2. Exhibit different contributions to low temperature performance
3. Typically detrimental to engine cleanliness
4. Selection of VM may benefit fuel economy
5. VM diluent contributes to finished oil volatility
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