Crankcase Lubricant Formulation
Agenda

01 | Industry value chain and organisation

02 | Developing a balanced lubricant formulation

03 | Product development process

04 | Summary
Oil and Additive Industry Value Chain

New requirements drive innovations by engine manufacturers and the lubricant industry for the consumer

Product Flow

New requirements:
- New environmental legislation
- New hardware requires higher quality oil

Requirement Flow:
- Government / legislators
- Engine builders
- Industry committees
- New oil specifications

Flow:
- Integrated petroleum companies
- Additive component suppliers
- Additive companies
- Lubricant companies
- Lubricant sale channels
- Vehicle owners

New additves
New oils

Requirement setters
Lubricant users
Lubricant supply
Vehicle owners

Performance you can rely on.
# Industry Organisations

<table>
<thead>
<tr>
<th>Europe</th>
<th>North America</th>
<th>Asia Pacific - China</th>
<th>Asia Pacific - Japan</th>
<th>Asia Pacific - India</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Additive</strong></td>
<td><strong>Oil</strong></td>
<td><strong>Engine</strong></td>
<td><strong>Testing</strong></td>
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<tr>
<td>ATC</td>
<td>ATIEL</td>
<td>ACEA</td>
<td>CEC</td>
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<tr>
<td>- Lubricant and Fuel Additives</td>
<td>- Code of Practice for CEC tests</td>
<td>- Light and Heavy Duty</td>
<td>- Extensively used in Europe</td>
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<tr>
<td>- Code of Practice for ACEA Engines oils</td>
<td>- Code of Practice for ACEA Engines oils</td>
<td>- Issues ACEA Sequences</td>
<td>- Board inc. ATC, ATIEL and ACEA IP</td>
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<td>- Technical issues related to lubricant industry in Europe</td>
<td>-</td>
<td></td>
<td>- Oil analysis test methods</td>
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<td><strong>ACEA EXTENDED WORKING GROUP – CONSULTS WITH ATC AND ATIEL</strong></td>
<td></td>
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<td>- GFC</td>
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<td></td>
<td></td>
<td></td>
<td>- Bench tests for French industry</td>
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<td><strong>NA – SPEC SETTING</strong></td>
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<tr>
<td>ACC</td>
<td>API</td>
<td>EMA</td>
<td>ATSM</td>
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<td>- Petroleum Additive Panel (PAP)</td>
<td>- All aspects of N.A. oil and gas industry</td>
<td>- Mainly HD</td>
<td>- Engine and Analytical tests</td>
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<td>- Code of Practice for ASTM tests</td>
<td>- EOLCS for Engine Lubricants</td>
<td>- Car and Light Duty</td>
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<td></td>
<td>- Issues API S, C, &amp; F</td>
<td>- Own Spec based on API</td>
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<td>- Donut and Starburst</td>
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<td>IIMA</td>
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<tr>
<td>- Trade organisation for smaller oil companies in NA</td>
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<td><strong>Asia Pacific – Japan</strong></td>
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<td><strong>JAMA</strong></td>
<td><strong>CTMC</strong></td>
<td><strong>JASO</strong></td>
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<td>- Develops lubes specifications</td>
<td>- Light, HD and Motorcycle</td>
<td>- China Test Monitoring Centre</td>
<td>- Japanese Tests</td>
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<td>- Develops Lubes Spec</td>
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<td><strong>Asia Pacific – China</strong></td>
<td><strong>CLSAC</strong></td>
<td><strong>JPI</strong></td>
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<td>- Chinese Lubricant Standards Alliance Committee</td>
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<td>- Bench and Analytical tests</td>
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<td>- Bureau of Indian Standards</td>
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Developing a New Lubricant Formulation

Oil must meet performance targets:
- Engine test
- Bench test

Each test requirement typically demands something different from lubricant performance

‘The Finished Oil’

- Base Oil: 60-90%
- Viscosity Modifier & flow improver: 5-15%
- Additive Package: 5-25%

Key is balancing the additives and other constituents for the application

Dispersant
Detergent
Antiwear
Antioxidant
Friction Modifier
Other Additives
Example of a formulation problem

Suppose that, in a formulation development*

- We need to pass three tests: **Test 1, Test 2, Test 3**
- For this particular product type, we traditionally use only two additive components: Alpha and Beta
- In scoping work we can identify combinations of Alpha and Beta that can pass **Test 1** and **Test 2** together
  - However none of these combinations can pass **Test 3** and this is a major issue for the project
- This is illustrated in a plot in the next slide

*(This example is highly idealised in order better to illustrate principles of formulation)*
Example of a formulation problem

Plot of the passing regions of “Formulation Space” for each test. Using components Alpha and Beta

Test 1 & Test 2 can be passed together, in this region. This overlap region is usefully large.

Test 3 can be passed, but not with a formulation that passes the other tests.

There is no formulation above that can pass all three tests together. This is a problem for this project.
How can lubricant formulation be used to overcome performance challenges?

Later, in the same development

- A colleague has discovered that the response of Test 3 to Alpha and Beta can be altered beneficially by adding 1% of a new component, Gamma, to the system.
- We therefore add 1% of Gamma to the system and re-explore the formulation space of each test across differing treat rates of Alpha and Beta.
- We see what happens in this case, in the next slide.
How can lubricant formulation be used to overcome performance challenges?

Plot of the passing regions of “Formulation Space” for each test. Using components Alpha, Beta, with 1% m Gamma

1. The passing region of Test 3 has now moved to a more useful place.

2. A region of formulation space can pass all three tests.

3. However, the use of Gamma has also changed the response shape of Test 2.
Concept of formulation balance

- Demonstrates how addition of a component can have a positive effect on one test but also a negative effect on another.

- Very common occurrence in crankcase formulations and the skill of the formulator is to set an appropriate balance between all the various opposing effects.

- In a development project where there can be 50 tests and 10 or more additive components, the task of achieving balance is not always straightforward.
Formulation Balance

Examples

Potential Positive Effects

- Soot induced oil thickening, Sludge control
- Acid control
- Piston cleanliness
- Anti-rust
- Fuel economy
- Film thickness (viscosity contribution)
- Fuel economy

Potential Negative Effects

- Fuel economy, Fluoroelastomer seals
- Particulate filter blocking
- Wear
- Oil haze
- Package instability
- Oil haze
- Viscosity loss on shear
- Piston cleanliness

Dispersant Mixture

Overbased Detergent Mixture

Organic Friction Modifier

Viscosity Modifier
Formulation Aspects
Base stock

Viscometrics
- Tailored to meet SAE grade
- Deliver low temperature properties

Volvatility
- Key to control evaporation
- Lower W-grades have higher volatilities for a given base stock type
  - 0W-30 > 5W-30
- Reduction with low volatility base stock types
  - PAO (expensive)

Engine and bench test performance
- Higher quality base stocks can deliver improved:
  - Oxidation stability
  - Cleanliness

Performance you can rely on.
Formulation Aspects
Viscosity modifier

Often, customer logistics impact choice of VM

Impacts engine performance such as cleanliness and fuel economy

Sufficient contribution to High Temperature High Shear (HTHS) viscosity SAE grade

Shear stability within specification limits

VM choice can affect wax in cold temperatures

VM diluent oil contributes to finished oil volatility

Performance you can rely on.
Formulation Aspects
Detergent systems

Detergent role

• **Neutralise** acidic species
• Minimise high temperature engine deposits
• Provide supplementary anti-oxidant properties

Key considerations

• Detergent type
• TBN limits
• Ash contribution
• Stability
Formulation Aspects
Dispersant systems

Levels and types of dispersant in the formulation are chosen to provide a balance of properties:

Positive attributes
- Control of soot-induced oil thickening
- Black sludge control
- Piston and engine cleanliness in key tests

Other aspects for consideration
- Viscosity at cold temperatures
- Fluoroelastomer performance
- Fuel economy
Formulation Aspects
Other components

**Anti-oxidant and Anti-wear**

- **Anti-oxidants** aminic and phenolic additives commonly used
  - Treat minimised due to cost
  - **Other components** also have anti-oxidant properties
- **ZDDP’s** highly effective anti-wear and anti-oxidant additives
  - Phosphorus and Sulphur limits common to protect after treatment systems

**Other additives**

- **Friction modifiers** may be organic or contain metal
  - Anti-wear performance may be affected by the addition of surface active components
- Others include
  - **Corrosion inhibitors**
  - **Anti-foam**
  - **Demulsifiers**
  - **Seals fixes**
  - **Pour point depressants**
Formulation Aspects
Stability / harms

Once formulation is defined, essential to check that package and oil are stable and assess ‘no-harms’ of the additive combination

Stability

• Haze or formation of visible layers early indicators of instability
• Detergent overbased material can form sediment
• Friction modifiers can induce stability issues

Harms testing

• Early lab testing for unexpected effects recommended
• As a minimum this will include seals, foaming and corrosion tests
Performance you can rely on.

Oil Appearance

- Clear and bright
- Slightly hazy
- Very hazy
- Sediment
- Phase separation
- Fish eyes
Formulation for Key Engine Tests

Some examples of engine tests in current ACEA and API specifications and the key oil properties that they probe are listed below.

### Passenger Car Motor Oil

<table>
<thead>
<tr>
<th>Property</th>
<th>Relevant test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black sludge</td>
<td>M271SL, Seq. VH</td>
</tr>
<tr>
<td>Soot induced oil thickening</td>
<td>DV6</td>
</tr>
<tr>
<td>Piston cleanliness, ring sticking</td>
<td>VW TDI, EP6</td>
</tr>
<tr>
<td>Oxidative oil thickening</td>
<td>Seq. IIIH</td>
</tr>
<tr>
<td>Valve train wear</td>
<td>OM646LA, Seq. IIIH, Seq. IVB</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>M111FE, Seq. VIE</td>
</tr>
<tr>
<td>Bearing corrosion</td>
<td>Seq. VIII</td>
</tr>
</tbody>
</table>

### Heavy-duty Diesel Oil

<table>
<thead>
<tr>
<th>Property</th>
<th>Relevant test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soot induced oil thickening</td>
<td>Mack T8E, Mack T-11</td>
</tr>
<tr>
<td>Filter plugging</td>
<td>Cummins ISM</td>
</tr>
<tr>
<td>Piston cleanliness, ring sticking</td>
<td>OM501LA, Cat C13, Cat 1N</td>
</tr>
<tr>
<td>Valve train wear</td>
<td>Cummins ISM, Cummins ISB, RFWT, OM646LA</td>
</tr>
<tr>
<td>Ring/liner wear</td>
<td>OM501LA, Mack T12</td>
</tr>
<tr>
<td>Aeration</td>
<td>EOAT, COAT</td>
</tr>
<tr>
<td>Oxidative oil thickening</td>
<td>Volvo T-13</td>
</tr>
<tr>
<td>Bearing corrosion</td>
<td>Mack T12</td>
</tr>
</tbody>
</table>

Further testing requirements, not listed here, may include OEM requirements, either in-house OEM engine tests or OEM field trials.
Demands on the Lubricant Continue to Evolve

As engine design and operation evolve, so too do the challenges faced by the lubricant.

Recent examples include:
- After-treatment compatibility
- Fuel economy improvement
- Low speed pre-ignition
- Electrification

In some cases existing lubricant technologies meet changing demands. However, new generation engines can drive the development of new lubricant formulations.

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Product Development Program Stages

Technology Development Stage

- Ideally consider a range of target options to identify correct balance between risk and opportunity
- Time spent here doing a rigorous analysis pays dividends later
- This part could be either minimal or extremely extensive depending on existing knowledge base

- Agree targets
- Analyse issues and devise plan for this stage
- Perform understanding work on key tests: (covers engine- & laboratory specification tests & predictive screener tests)

Qualification Development Stage

- Industry Codes are complex and it is essential to plan carefully the testing program to ensure compliance
- The time required here depends on the size of the test program
- Run full test program and obtain OEM approvals & industry qualifications

- Select Prototype Candidate
- Devise testing Plan

Time (not necessarily to scale)
Product Development Program

Time and cost

Lower-end complexity and challenge

Single ACEA specification added to existing product
Assume no technology development work
- Testing cost (= once-through costs): **400k USD**
- Elapsed time to complete: **2-3 months**

Higher-end complexity and challenge

Product to meet combinations of OEM specifications with extensive testing requirements
Assume considerable technology development work
- Total project cost: **> 5 million USD**
- Elapsed time to complete: **> 3 years**
Codes of Practice Framework

**Codes of practice**
- Assures the quality of the tested product

**Principles include**
- All test work should be visible to the customer
- Any read-across of results should not compromise the quality of the product

- Represent both European and North American Additive companies with own Codes of Practice
- Allowable changes to the additive package and constituent components, plus changes to viscosity modifiers

- Equivalent Codes of Practice from Oil Marketer perspective
- Include guidelines for base oil interchange (BOI) and viscosity grade read across (VGRA)
- Other aspects such as data reporting and (for API) licensing
Summary

Crankcase formulation: what’s it all about?
• Satisfying huge number technical requirements which often oppose each other
• Recognising concept of formulation balance
• Understanding positive and negative impacts of the individual components
• Planning very carefully the technology development scoping work as well as the detail of the qualification test work
• Investing potentially very large engine test budgets where programs are complex and technically challenging
• Adhering to industry codes of practice
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