Biodiesel Validation in Caterpillar Engines

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Hind Abi-Akar
Caterpillar Inc.
Marketing and Product Support Division
Caterpillar Diesel Engines - Product Line

- 400 Series (3.7 - 45 kW)
  - 3116/3126/C-7 (86 - 313 kW)
- 800 Series (39 - 60 kW)
  - C-9/C-11/C-13 (227 - 492 kW)
- 1100 Series (49 - 186 kW)
  - 3200 Family (93 - 336 kW)
- 3200 Family (63 - 300 kW)
  - 3300 Family (63 - 300 kW)
  - 4000 Series (322 - 1886 kW)
  - M20 (1020 - 1710 kW)
- 3500 Family (507 - 2500 kW)
- 3600 Family (1350 - 7200 kW)
- M25 (1800 - 2700 kW)
- M32 (2880 - 8000 kW)
- M43 (5400 - 16200 kW)

Caterpillar®

Perkins®

Mak®
Caterpillar Engine Applications
New Product Introduction

- Diesel Engines and new product, for worldwide applications, are validated on diesel fuels per ASTM D975 or EN590
- Emissions Certification is conducted using EPA prescribed certification fuel

- Fuels other than diesel present a challenge for design and validation efforts
  - The fuels must be viable, available, and of consistent characteristics
Validation of Biodiesel

Approach to validation:

- **Analysis**: Risk assessment, modeling
  - Rigorous 6 Sigma methodology; FMEA for potential applications and blends
  - Development of analysis and testing procedures characterize the fuel and understand its potential performance and interactions
- **Bench tests**: Accelerated tests for stability, compatibility, etc.
- **Engine tests**: Accelerated cycles and Detailed assessment of components
- **Field testing**: Assessment of performance and analysis of components
- **Testing programs with the industry**: EMA, NBB, NREL, ASTM, etc.

Specification development
Guides and information
Communication with dealers
Biodiesel Early Testing

- 1997 Field test, 3406 on-highway truck application using B50 blend of soy methyl ester and #2 diesel fuel
  - >240,000 miles
  - Emissions and BSFC measurements
  - Engine power and performance assessment
  - Component Wear and deposits
    - No adverse effects were found
- 2002: Program to assess seal materials compatibility in B50 soy methyl ester
  - Quantification of the adverse effects on Nitrile rubber materials
  - Identification of appropriate seal materials
## Analysis - Quality Function Deployment

<table>
<thead>
<tr>
<th>Customer / Business needs</th>
<th>Performance</th>
<th>Emissions</th>
<th>Fuel system</th>
<th>Aftertreatment</th>
<th>Lubrication system</th>
<th>Components</th>
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9=strong, 3=moderate, 1=weak
### Analysis - Quality Function Deployment

#### Considerations
- Biodiesel quality
- Biodiesel blend level
- Biodiesel stock
- Etc.

#### Risk Assessment
- Identify validation needed
- (Bench, engine, field tests, etc.)

#### Customer/Business Need
- Engine Performance
- Emissions
- Fuel System
- Aftertreatment
- Engine lubrication
- Storage & management
- Etc.

#### Reconciling Customer and business requirements and tests and validation
## Analysis – Failure Modes and Effect Analysis (FMEA)

<table>
<thead>
<tr>
<th>Process Step/Input</th>
<th>Potential Failure Mode(s)</th>
<th>Effects</th>
<th>Severity</th>
<th>Potential Cause(s)</th>
<th>Probability</th>
<th>Current Controls</th>
<th>Detected</th>
<th>RPN</th>
<th>Recommended Action(s)</th>
<th>Action(s) Taken</th>
<th>Severity</th>
<th>Probability</th>
<th>Detection</th>
<th>RPN</th>
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**Legend:**
- Severity (Sev)
- Probability (Prob)
- Detection (Det)
- RPN (Risk Priority Number)
## Detailed analysis of potential failures on B30 and other blends

## Validation, Tests and corrective actions

- Identify test engines: engine models and fuel blends
- Bench tests:
  - Pistons and valves deposits
  - Fuel systems compatibility
  - Oxidation stability of biodiesel
  - Seals and hoses compatibility and life
  - Compatibility and effects on engine oils
  - Emissions
  - Etc.
Accelerated Engine Tests

HD, MD and smaller engines

Equivalent to 100,000 miles

HD engine test, B20
Characterization

Chemical analysis
Development of new testing methods
Understanding the mechanisms of chemical interactions
  ❖ Impact on oils
  ❖ Impact on emissions
  ❖ Impact on deposits
  ❖ Developing procedures for measurements

Soot analysis
Raman Spectroscopy
Field Testing

- **Mine applications**
  - B100, RME
  - B20: Engine power, fuel consumption, oil analysis, general observations
  - Multiple sites using biodiesel – communication with customers

- **Construction sites**
  - Various blends
    - Engine power, oil analysis

- **Bus applications**
  - Successively increasing blend levels
    - Monitor performance, components, power, etc.
Biodiesel Use in Caterpillar Engines

Engines manufactured in 2006 and earlier:

1. Up to B30 maximum blend level acceptable for:
   - ACERT Technology: C7, C9, C11, C13, C15, C18, C27, C32
   - 3114, 3116, 3126, 3176, 3196, 3208, 3306, C-9, C-10, C-12, 3406, C-15, C-16, C-18, 3456, 3408, 3412, 3500 Series, C175 Series, 3600 Series, C280 Series, CM20, CM25 and CM32

2. Up to B20 maximum blend level acceptable for:
   - C0.5 through C2.2 and C4.4 mechanical fuel injection equipped engines that meet Tier3/Stage 3a emissions regulations

3. Up to B5 maximum blend level acceptable for:
   - C0.5 through C2.2 and C4.4 mechanical fuel injection equipped engines that meet Tier2/Stage 2 or earlier emissions regulations
   - C4.4 and C6.6 ACERT and C3.4, 3003-3034, 3044, 3046, 3054, 3056, 3064 and 3066 engines
Biodiesel Use in Caterpillar Engines

Engines manufactured in 2007

1. Requirements for Non-Road 2007 model engines:
   - No change relative to 2006

2. Requirements for On-Highway 2007 model engines:
   - Finalized extensive tests of 07 engines, HD, MR, on-truck, etc.
   - Expected announcement of up to B20
   - Biodiesel must meet Cat and/or Industry specifications and BQ900 Quality requirements
Biodiesel Requirements for use in Caterpillar engines

- Biodiesel blend stock must meet requirements listed in the Caterpillar biodiesel specification,* ASTM D6751, or EN 14214
- Final biodiesel blend must meet requirements for distillate diesel fuel published by Caterpillar, ASTM D975, or EN590
- Distillate diesel used for blending must meet Caterpillar requirements, ASTM D975, or EN590

For blends above B5, oil analysis is strongly recommended. For blends above B20 oil analysis is required to ensure oil change intervals are appropriate

Biodiesel: Esterified vegetable oils from a variety of feedstocks including soybean, rapeseed (primary base stocks), animal tallow, waste cooking oil, etc.
Warranty Coverage with Biodiesel

- Warranty covers material and workmanship defects:
  - Failures caused by other factors, including lack of proper maintenance (use of improper fuel, oil or filters, lubricants and coolant) are not covered by warranty.

- Use of acceptable biodiesel blends does not affect Caterpillar warranty for materials and workmanship

Failures that result from the use of any fuel are not Caterpillar factory defects. Therefore, the cost of repair would not be covered by Caterpillar warranty.
Caterpillar supports the development of B20 Biodiesel specification

Caterpillar supports the strengthening of B100 specification ASTM D6751: addition of the oxidation limits and limits on the alkali metals

Caterpillar is working with the industry to develop tests and to better understand the impact of biodiesel on engines
Sustainability

- Support of biodiesel aligns with Caterpillar sustainability initiatives
- Biodiesel is an option to expand America's production of renewable fuels and lessen our dependence on imported energy
  - Farming practices have a major impact on the life cycle sustainability contribution of biodiesel and other alternative fuels
- Support continued efforts to strengthen biodiesel technical fuel standards
- Support efforts to increase quality and consistency of biodiesel fuels
Thank You!