Fleet Performance Results Using Biodiesel

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Office of FreedomCAR and Vehicle Technologies

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Agenda

1. Fleet Evaluation Team Background
2. NREL Fleet Test Activities
3. RTD B20 Evaluation Results
   • Project objectives and approach
   • Mileage accumulation, fuel economy
   • Road calls and maintenance
   • Fuel and fuel filter analysis
   • Lube oil analysis
   • Chassis dynamometer emission results
   • Conclusions
B20 Fleet Evaluation Team

• Early NBB requests of OEMs
  – Warranty support for B20
  – All wanted more field data
• Major OEMs, industry experts, and stakeholders participate
• Biodiesel proponents: “No B20 issues in the field”
• OEMs: “Prove it with quantifiable data”
• Active since 2003
• Gather information about the B20 usage experience
• Now known as the Biodiesel Blend Evaluation Team (BBET), with a focus on B20
# B20 FET Team Members

- Bosch
- Case New Holland
- Caterpillar
- Cummins
- DaimlerChrysler
- Delphi Diesel Systems
- Department of Defense
- Engine Manufacturers Association
- Fleetguard
- Ford Motor Co.
- General Motors
- International
- John Deere
- National Biodiesel Board
- NREL
- Parker - Racor
- Siemens Diesel Systems
- Stanadyne Corp.
- Volkswagen AG
- Volvo Truck
NREL’s Fleet Test and Evaluation Team

- Focused on evaluating advanced technologies in medium and heavy vehicle applications
- Main goals:
  - Facilitate the transition of advanced technologies from R&D to the marketplace
  - Provide potential users with accurate and unbiased information on vehicle performance and costs
- Fleet projects
  - Denver Regional Transportation District (RTD)
  - United States Postal Service (USPS)
  - St. Louis Metro
B20 Fleet Evaluation – Objectives

• Compare vehicles operating in the field on B20 and conventional diesel over 24 months:
  – Engine performance
  – Fuel economy
  – Vehicle maintenance cost
  – Fuel-induced variations in operation and maintenance
  – Lube oil performance
  – Emissions

• Exhibit high degree of experimental control in vehicle selection and duty cycle

• Aid engine OEMs in exploring effects of B20 on engine durability

• Aid potential B20 users in understanding costs, benefits, and differences in operation
B20 Fleet Evaluation – Approach

- Nine mechanically identical Denver RTD transit buses:
  - 2000 Orion V, Cummins ISM
  - Five operated on B20, four on diesel
- Dedicated to Skip Route in Boulder identical duty cycle
- RTD submitted data electronically from their internal database
  - Fuel, labor, parts
- In-use fuel economy and maintenance costs analyzed by NREL

- Fuel delivery and vehicle tank sample analysis
- Periodic oil sampling at drain interval and analysis
- Two study buses emissions tested on chassis dyno at NREL’s ReFUEL facility
Mileage Accumulation

Running Average Monthly Miles Per Bus

- 4,200 miles per month per bus
On-Road Fuel Economy

- 4.41 mpg Diesel, 4.41 mpg B20
Maintenance Costs – Total

- 24-month average maintenance costs:
  - $0.54/mile diesel, $0.51/mile B20
  - Diesel transmission repairs drive difference
Maintenance Costs – Engine, Fuel System

- 24-month average engine and fuel system maintenance costs:
  - $0.05/mile diesel, $0.07/mile B20

May 06: Failed injector, all 6 replaced
June 06: Scheduled cylinder head change, all 6 injectors replaced (again)
### Maintenance Costs – Engine, Fuel System

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>B20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel pump</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Fuel injector</td>
<td>1</td>
<td>13</td>
</tr>
</tbody>
</table>

- Injector discrepancy driven by replacement of full set, then cylinder head replacement
- No reason to suspect B20 fuel currently
  - Cummins tear-down analysis of 6-injector set that failed
Road Calls

- Average MBRCs are comparable
  - 3,197 Diesel, 3,632 B20
Fuel Analysis

- Biodiesel content of delivery samples scattered
  - Changes to fuel blending & sampling implemented May ‘05
- Vehicle samples taken are near B20
- **Knowledge of sampling point is important**
Fuel Analysis

- March 2006 vehicle fuel sample analysis
  - Acid value, peroxides, aldehydes (alkanals) determined by Saftest
  - Acid value and peroxides consistently low as compared to NREL B20 fuel quality survey
  - Alkanals indicate some oxidative degradation, but are not high

<table>
<thead>
<tr>
<th>Vehicle Number</th>
<th>B100 Content Volume %</th>
<th>Acid Value mgKOH/g</th>
<th>Peroxide Saftest™ ppm</th>
<th>Aldehyde Saftest mmol/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2207</td>
<td>20.3</td>
<td>&lt;0.1</td>
<td></td>
<td>58.212</td>
</tr>
<tr>
<td>2208</td>
<td>18.4</td>
<td>&lt;0.1</td>
<td>13.22</td>
<td>57.902</td>
</tr>
<tr>
<td>2209</td>
<td>17.4</td>
<td>&lt;0.1</td>
<td>11.59</td>
<td>55.696</td>
</tr>
<tr>
<td>2210</td>
<td>18.7</td>
<td>&lt;0.1</td>
<td>16.75</td>
<td>73.35</td>
</tr>
<tr>
<td>2211</td>
<td>19.7</td>
<td>&lt;0.1</td>
<td>11.42</td>
<td>61.546</td>
</tr>
</tbody>
</table>
Fuel Analysis

- Composite March 2006 vehicle fuel samples had more detailed analysis
  - Higher cetane number
  - Lower sulfur content
  - 2.4% lower B20 energy content

<table>
<thead>
<tr>
<th>Analysis</th>
<th>ASTM Method</th>
<th>B20 Composite</th>
<th>Diesel Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water and sediment vol %</td>
<td>D2709</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Cloud point ºC</td>
<td>D2500</td>
<td>-13</td>
<td>-14</td>
</tr>
<tr>
<td>Sulfur ppm</td>
<td>D5453</td>
<td>324</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D2622</td>
<td>272</td>
<td></td>
</tr>
<tr>
<td>Aromatics vol %</td>
<td>D1319</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>Olefins vol %</td>
<td></td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Saturates vol %</td>
<td></td>
<td>73.1</td>
<td></td>
</tr>
<tr>
<td>C mass%</td>
<td>D5291</td>
<td>84.7</td>
<td>86.6</td>
</tr>
<tr>
<td>H mass%</td>
<td></td>
<td>12.9</td>
<td>13.2</td>
</tr>
<tr>
<td>Derived cetane number</td>
<td>D6890</td>
<td>51</td>
<td>48</td>
</tr>
<tr>
<td>LHV BTU/lb</td>
<td>D240</td>
<td>17,860</td>
<td>18,307</td>
</tr>
</tbody>
</table>
B20 Fuel Filter Plugging

Three filter plugging events:
1. April 2005 – Two buses
   - Brown slime. Cold snap?
   - Biocide applied to next fuel delivery

<table>
<thead>
<tr>
<th>Bus</th>
<th>Biodiesel</th>
<th>CFPP °C</th>
<th>Water (ppm)</th>
<th>Bug Alert</th>
</tr>
</thead>
<tbody>
<tr>
<td>2208</td>
<td>16.9</td>
<td>-25</td>
<td>77</td>
<td>27 (low)</td>
</tr>
<tr>
<td>2209</td>
<td>19.2</td>
<td>-25</td>
<td>88</td>
<td>57 (low)</td>
</tr>
<tr>
<td>2210</td>
<td>20.3</td>
<td>-25</td>
<td>97</td>
<td>1 (very low)</td>
</tr>
<tr>
<td>2211</td>
<td>15</td>
<td>-30</td>
<td>78</td>
<td>93 (low-med)</td>
</tr>
</tbody>
</table>

- Filter residue analysis indicated presence of plant sterols
B20 Fuel Filter Plugging

2. June 2005 – One bus
   – B20 storage tank fuel level low
   – Sediment plugged dispenser and fuel filters
   – Fuel filter samples collected
   • Preliminary GC-MS results indicate high levels of phytosterols

3. July 2006 – Two buses
   – B20 storage tank fuel level low (end of project)
   – Sediment plugged fuel filters (Soap?)
   – Fuel filter samples, fuel storage tank samples collected
   • Preliminary GC-MS results indicate high levels of phytosterols
Lube Oil Analysis

- One set of oil drain samples (March/April 2006) analyzed by Cummins
- Exponential decay of ZDDP and TBN consistent with previous Cummins testing
- No difference in ZDDP decay between diesel and B20 samples
- TBN decay may be occurring more slowly in B20 samples
# Lube Oil Analysis

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>B20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Dilution</td>
<td>Low</td>
<td>Lower</td>
</tr>
<tr>
<td>Metals (evaporative)</td>
<td>No difference</td>
<td>Lower @ high mileage</td>
</tr>
<tr>
<td>Metals (engine wear)</td>
<td>Low</td>
<td>Lower @ high mileage</td>
</tr>
<tr>
<td>Soot</td>
<td>Low</td>
<td>50% lower</td>
</tr>
<tr>
<td>Viscosity, Viscosity Index</td>
<td>No difference</td>
<td>No difference</td>
</tr>
</tbody>
</table>
Bus Chassis Dynamometer Testing

- Two in-use buses tested
- Cummins ISM 2000 engine – no EGR
- In-use B20 vs. diesel fuel

![Graph showing speed over time](Graph.png)

<table>
<thead>
<tr>
<th></th>
<th>Skip Bus Route</th>
<th>CSHVC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Avg Speed</strong></td>
<td>15.6 mph</td>
<td>14.2 mph</td>
</tr>
<tr>
<td><strong>Max Speed</strong></td>
<td>40 mph</td>
<td>44 mph</td>
</tr>
<tr>
<td><strong>Stops/Mile</strong></td>
<td>0.78</td>
<td>0.75 (^1)</td>
</tr>
</tbody>
</table>
Bus Chassis Dynamometer Test Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline Conventional Diesel Fuel</th>
<th>B20 Fuel</th>
<th>Error bars show 95% confidence interval of the mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx (g/mi)</td>
<td>≈ -4.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THC X 10 (g/mi)</td>
<td>≈ -29.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO (g/mi)</td>
<td>≈ -24.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM X 10 (g/mi)</td>
<td>≈ -18.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Economy (mpg)</td>
<td>≈ -2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• No significant difference between B20 and diesel baseline:
  – On-road fuel economy
  – Reliability (road calls)
  – Total maintenance costs
  – Fuel System and engine maintenance costs
• Filter plugging issues – plant sterols one potential cause
• Early B20 splash-blending issues, generally B20 in tank
• Limited lube oil data suggests no harm with B20 use, some potential benefits
• Significant emissions reductions including NOx
• SAE Paper 2006-01-3253
Information

- SAE Paper 2006-01-3253 100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20)

- Contact information
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