UC-Riverside PEMS Workshop
March 24, 2011

In-Use Testing Experiences
Joel Squire, Caterpillar, Inc.
Agenda

- Overview of Caterpillar’s in-use testing programs
- Performance Comparison of PEMS
- PEMS Data Reduction Programs
- Specific experiences with AVL PM-PEMS
- Non-road in-use testing Challenges
Caterpillar’s IUT Program at a Glance

**PEMS Applications**
- On-Highway In-Use Testing
- Non-Road Applications
- Marine Field Testing

**PEMS Instruments**
- Sensors Inc. SEMTECH-DS
- Horiba OBS, and TRPM
- AVL 494 (483 Microsoot Sensor and Gravimetric Filter Box)

Comparisons shown using “blind” approach
• Results do not reflect “out of the box failures” (Only failures that required a complete retest)

• Still not comfortable with PEMS reliability

• Further development is required
PEMS Data Processing

• Data reduction programs are a key element for regulatory compliance programs

• EPA report generation is a requirement, but complex
  – Would like to see this simplified (upcoming Non-Road rule, improvements to Truck, etc.)

• Caterpillar has experience with three different PEMS data reduction programs
  – Sensors
  – Horiba
  – AVL

• Significant differences between data-processors
  – Required EPA Report Creation abilities are poor or lacking
  – NTE Event determination can be different between processors
  – Basic vs. Advanced plotting features
  – Importing foreign data files
  – Would prefer a built in engineering units conversion utility
  – Calculation errors and software bugs continue to plague all processors.
  – Ability to use multiple calculation schemes
    • Mass calculations (EPA Method 2 and 3)
    • US NTE/European WBW schemes
AVL 494 PEMS Experience

• AVL PM-PEMS Overview
  – AVL 483 Microsoot sensor (Real-time measurement)
  – Gravimetric Filter (constant dilution partial flow)
  – Applies Total PM correction to the AVL 483 signal for real-time resolution of PM

• Pros
  – Setup and operation is relatively less complicated than other options
  – Enclosures are rugged (dust/drip proof), Ideal for Non-Road Machinery
  – Heated Sample line is very flexible and durable
  – Can be operated independently from gaseous PEMS
  – Only available PM PEMS that can use EPA Method 3 (ECM Fuel Rate)
  – Can upgrade existing AVL 483 to a PM-PEMS

• Cons
  – Filter pucks are very small and hard to handle (leads to filter mishandling)
  – Some dust still gets into the unit (Non-Road Applications)
  – Heated Sample line needs to be longer (Cat Only has a 2 meter line)
  – Needs a separate host computer to log a data file
  – Has problems operating in somewhat extreme temperatures (hot/cold)
AVL 494 PEMS Experience
Concerto Processor

- Data Processing
  - Concerto can process both Gaseous and PM Data
    - Imports data from other Gaseous PEMS
  - Developed for the on-highway in-use test reporting
  - Non-Road in-use testing templates need to be added
    - US Non-road In-use rule will require new template (dev. time)
  - Can also perform work-based-window calculations
    - Required for European in-service conformity
### Periodic Calibrations and Checks

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Interval</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFO Calibration (Filter Flow, MSS Flow)</td>
<td>365 Days</td>
<td>NIST Traceable Manufacturer Cal.</td>
</tr>
<tr>
<td>Calibration of Dilution MFC</td>
<td>Pre-Test</td>
<td>&quot;Mirrored&quot; to internal CFO's</td>
</tr>
<tr>
<td>Sample Flow Check</td>
<td>35 Days</td>
<td>Within +/- 3% accuracy at each dilution ratio</td>
</tr>
<tr>
<td>Filter Temperature Linearity Check</td>
<td>35 Days</td>
<td>Meets 1065.307 Linearity Criteria</td>
</tr>
<tr>
<td>Vacuum Leak Check</td>
<td>Pre-Test</td>
<td>Protocol built into the AVL PEMS</td>
</tr>
<tr>
<td>Absorber Window Calibration for Micro Soot Sensor</td>
<td>Pre-Test</td>
<td>Within +/- 1% accuracy</td>
</tr>
</tbody>
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- We are looking for a solution to perform the CFO calibration in-house as opposed to sending out.
- Currently unable to perform the filter temperature linearity due to equipment constraints.
- May be useful to have ability to perform background check before sending the unit into the field.
Non-Road In-Use Testing Challenges

Ambient Conditions
PEMS will have increased exposure to ambient conditions, more so than on-highway (No ram air or air-conditioned cab)
Vibration, dust will drive additional maintenance and failure costs to PEMS
Ambient Temps can be drastically different on machine

Temperature deltas on a Non-road Application

PEMS temperature is measured near air intake via weather probe
Actual ambient temperature is acquired from local weather station
Even with PEMS modifications, PEMS still failed
High Ambient Temps on Excavator on a 78 Deg F Day.

- Excavator was used to simulate truck loading and trenching applications
- PEMS mounted on top of cab
- An environmental case was used to protect the PEMS from water and dust.
- End covers of the environmental case still had to be removed, exposing the PEMS, to keep the Chiller from overheating.
- PM PEMS was more sensitive to the heat and was removed from the machine.
- Dilution control failed.

Flow meter and sample line

Gaseous PEMS

PEMS originally placed here

Gasoline Generator
Expected Non-Road In-Use Testing Challenges

**Agricultural Applications**
- Strict harvest Schedule
- Lack of use during non-harvest seasons

**Customer Compensation for Large Machinery**
- Monetary loss for machine taken out of service is significant, potentially tens of thousands of dollars per day.
Summary

PEMS Maintenance/Failures continue to be costly
$13,097/unit for repairs & calibrations in 2010 alone
Significant time spent re-testing engines
We should not have to bring 2 PEMS on each test assignment

The cost of performing in-use testing is still quite high.

Data Processors are an important part of the PEMS package
But not without their problems either…
…Especially in terms of EPA report generation

Non-Road in-use testing will be very challenging
More so than on-highway in terms of recruiting and testing engines

We would like to ask regulatory agencies to simplify the reporting requirements as more experience is gained