Materials-Enabled High-Efficiency Diesel Engines (CRADA with Caterpillar)  
Project ID – PM 06

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Overview

Timeline

- Begin transition of lab space to engine research cell - October 2008
- Commissioning of engine research cell with operational engine & dynamometer – March 2009
- Engine is operational
- Begin material/component evaluation – April 2009

Budget

- Funding received in FY2008
  - DOE - $400K
  - ORNL (cell infrastructure) - $1000K
- Funding received in FY2009
  - DOE - $180K

Technical Targets

- Develop supporting materials technology to enable Heavy-Duty diesel efficiency of 55%, while meeting prevailing EPA emission standards (by 2012)
- Engine life greater than 1 million miles (by 2012)

Barriers

- Inadequate design & performance data, test methods, tools, and durability data for widespread application of advanced materials
- Advances in thermal management and advanced combustion necessitate the development and utilization of advanced materials
- Material costs

Partners

- Caterpillar
  - Materials Performance & Advanced Powertrain Component Development Groups
- In-kind contributions have consisted of two 600 hp DC dynamometers & a C15 ACERT engine with open control
Study Objective

*Improve diesel engine performance, efficiency, and emissions through the application of materials enabling technologies. The goal is to reach 55% efficiency in a heavy-duty diesel engine.*

- For FY08:
  - Completed transition of bare laboratory space to a heavy-duty engine research cell

- For FY09:
  - Commission C15 ACERT diesel engine by initiating baseline experimentation
  - Evaluation of thermal recovery benefit of a selected ceramic thermal barrier coating on exhaust components
Milestones

• **Milestones for FY2008:**
  • Complete installation of engine research cell (completed Sep-08)
    – Finalize cell design (including installation of control room)
    – Proper permits in place
    – Procure & install infrastructure
      • Additional power
      • Air handling system
      • Water tower installation
      • Noise suppression
      • ESH review
      • Instrumentation & Analyzers
      • Gas bank
      • Dyno controllers
      • Fuel handling equipment
      • Plumbing for fuel & water
      • Bedplate setup
      • Electrical wiring
      • Safety features
      • Room ventilation
      • Engine/Dyno coupling

• **Milestones for FY2009:**
  • Commissioning of engine and dynamometer (April-09)
  • Baseline experimentation (May-09)
  • Evaluation of thermal barrier coating for selected exhaust components (Aug-09)
Approach

This CRADA makes use of engine/combustion and materials expertise at Caterpillar and ORNL to provide new insight into the integration of these technologies through a materials-by-design approach to high temperature, high pressure engine operation.

Caterpillar WFO

- Engine & tools
- Materials selection
- Technical support

Oak Ridge National Laboratory

- Engine performance
- Diagnostics & analysis
- Materials characterization

Separate but highly complementary effort to provide advanced modeling support

Materials & Engines approach provides a more complete understanding to better improve combustion, thermal management, emissions & cost reductions.
Technical Accomplishments for FY-08

- Complete installation & commissioning of experimental cell infrastructure:
  - Gas Handling System (including internal plumbing)
  - Water Tower (including internal plumbing)
  - Fuel Storage & Delivery System (including internal plumbing)
  - Room Ventilation & Exhaust (including ducting)
Technical Accomplishments for FY-08 (continued)

- **Completed construction of engine control room**
  - Added wall, windows, & noise suppression
  - Commissioned analytical bench
  - Added power, furniture & emissions bench
  - Dynamometer controllers added & commissioned

- **Completed dynamometer & engine installation**
  - Installed bedplate & mounted engine
  - Coupling adapter fabricated
  - Added additional power for dyno operation
Technical Accomplishments for FY-09 (so far)

- Data acquisition system installed
- Dynamometer & controller commissioned
- Water delivery system commissioned
- Engine has been instrumented
  - Temperature
  - Pressures
  - Flow rate
  - Chemistry
- Engine operational
  - Mar 13, 2009
Instrumentation diagram for ACERT engine
Activities for Next Fiscal Year

1. **Commission the engine “as-is”**
   - Evaluate & compare engine performance to Caterpillar specifications
   - Explore control parameters with engine performance
   - Thermal analysis of engine components (especially exhaust)
   - Commission bench analyzers, instrumentation & data acquisition system

2. **Install modified head**
   - Instrumented for pressure & temperature measurements
   - Explore control parameters with combustion behavior

3. **Begin materials performance evaluation**
Materials Evaluation Research Plan – Future Work

- **Selected material coating has the potential to:**
  - Reduce thermal losses
  - Reduce manufacturing cost
  - Improve durability

1. **Evaluate the performance of a coated component in exhaust system**
   (initial location is to be downstream of turbo)
   - Variables include:
     - Temperature
     - Exhaust flow rate
     - Transients
     - Exhaust chemistry

2. **Analyze component for structural integrity**
   - NDE
   - Microstructural analyses

3. **Temperature data entered into model to assess thermal management potential and identify locations for additional modifications**

4. **Expand research plan to additional components & materials**
A modeling activity will be utilized to identify further efficiency opportunities & material improvements

- This activity is part of the WFO project but analysis will also support this CRADA
- Provides component-by-component evaluation of thermodynamic losses/opportunities as well as full-system overview.
- Evaluation of experimental data
  » Characterize potential to recover/reduce thermal energy discarded to the environment.
- Thermal management of engine-system
  » Balance several technologies competing for the same thermal resources.

Example 2nd Law Distribution

- 36% Irreversibility (mixing, combustion, throttling, etc)
- 14% Availability Exhaust Flow
- 10% Heat Loss (engine block, head, intercooler, etc)
- 40% Indicated Work from Combustion

Example of exhaust availability for a Light-duty diesel

Exhaust Availability
(Fraction of Fuel Availability)

Exhaust Availability
(BIMEP (bar))

Engine Speed (rpm)
Summary

- We are establishing a unique CRADA with Caterpillar with the goal of evaluating new materials systems for improved engine efficiency
  - Combines ORNL materials and engine/combustion R&D expertise with industry partner
  - Similarly, materials and engine research staff at Caterpillar are also working together

- Installation of Cell infrastructure has been completed.
  - Caterpillar has provided ACERT C15 and associated hardware
  - Received substantial internal ORNL funding
  - Cell commissioning completed in December

- Baseline engine experiments begun early in 2009