Advanced Emission Reduction Technologies for Locomotives:

Fuels & Lubes

by

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Railroad Energy Consumption

* 1999 Class I Railroads:
  » 20,254 Locomotives
  » $3.75 \times 10^9$ Gallons Diesel Fuel Consumed
  » $= 185,120$ gallons/year/locomotive
  » Average Cost of $0.56 / gal

Source: AAR Railroad Facts 2000
RAILROAD REVENUE DOLLAR - 1999

Fuels & Lubes Overview

* Fuel-Saving Devices & Additives
* Brief review of previous work
* Recent fuel-effect studies
* Lubricating Oil Issues
* Future research areas
Fuel Saving Devices & Additives

* AAR Recommended Practice RP-503 “Locomotive Diesel Fuel Additive Evaluation Procedure”

* Transport Canada & ESDC “Simplified Fuel Additive Test”

* Tampering Provisions in EPA Locomotive Rule

* EPA-Required Registration of Fuels and Fuel Additives (211b)

AAR Recommended Practice-503

* Voluntary Procedure

* Phase I: Analyze Fuel Properties

* Phase II: Single-Cylinder Cat 1G2
  » A screening test to make sure the additive/device does not harm the engine - protects the more expensive locomotive test engines

* Phase III: EMD 2-567C Engine (fuel economy and exhaust emissions)

* Phase IV: EMD 12-645E3B or GE 127FDL fuel economy and exhaust emission tests

* RP-503 needs to be update to reflect EPA 40CFR92 locomotive exhaust emission procedures and requirements

* AAR RP-503 SwRI contact = John Hedrick (210) 522-2336 jhedrick@swri.org
**Simplified Fuel Additive Test**

* SFAT - Simplified Fuel Additive Test  
* Funded by the Transport Development Center of Transport Canada  
* Work performed by Engine System Development Center (ESDC) in Montreal  
* Based on Alco/Bombardier 1-251  
* Goal is to develop a less-expensive alternative to the AAR RP-503

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**EPA 211(b)**

* Sections 211(b) and 211(e) of the Clean Air Act require registration of motor vehicle fuels and fuel additives with the EPA  
* 40 CFR Part 79 -- Registration of Fuels and Fuel Additives  
* Applies to On-Highway Motor Vehicles  
* List of registered F/FA is available on EPA's web page:  
http://www.epa.gov/oms/regs/fuels/additives/web-dies.txt
EPA Locomotive Rule - Tampering

* Using a fuel additive or “fuel saving device” on a EPA-certified locomotive may constitute “tampering” under §92.1103

* If the additive or device contributes to the increase in emissions of a regulated pollutant, it is tampering…. “Subject to a civil penalty of not more than $25,000 for each violation”

* Make sure you have a “reasonable basis” to believe that you will not increase ANY of the regulated emissions before you use a product.

Questions: Fuel Saving Additives/Devices

* Is it registered with EPA under 211(b)?
  » Not a requirement, just a question.

* Has the product been evaluated using the AAR RP-503 procedure?

* Do you have a “reasonable basis” to believe that use of the additive or device will not constitute tampering under the EPA locomotive regulations?
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1972 - “Back to the Future”

* NOx reduction studies on EMD 2-567 for DOT & EPA (ASME 74-DPG-14)
* Retarded timing
* EGR (hot & cooled)
* Water Injection
* Boost air bleed

![Chart showing NOx reduction effects with different injectors]
Late 1970's Fuel Crunch!

* 1978 - Started "Alternative Fuels for Medium-Speed Diesel Engines" - DOE-FRA funding; AAR program planning

* 1980 - AAR member roads provide two test engines
  » EMD 12-645E3 - 2,500 hp
  » GE 7FDL12 - 2,500 hp

* 1981 - DOE & FRA funding ends - AAR assumed sole sponsorship

AAR Fuels Program
1978-1987
AAR Fuels Research at SwRI

* Broadened specification diesel fuels
  » Fuel characterization
  » 72-hour idle tests
  » 500-hour screening tests
  » Field tests
  » Very limited exhaust emissions testing

RESULT = AAR FUELS MANUAL

Broadened-Specification Diesel Fuels
1986 Dual-Fuel EMD

* DOE-funded project
* EMD 2-567C engine
* High-Pressure, Dual-Fuel (diesel & LNG) injector developed
* Achieved full power with 99% gas substitution w/o reducing CR
* SAE 872041

BN DUAL-FUEL LOCOMOTIVE

* ECI Conversion
* 2,250 kW
* Dual-Fuel
* Revenue Coal Service 1992-95
EMD DUAL-FUEL LOCOMOTIVE

MK Rail 1200G LNG Switcher

* CAT 3516G
* 1,000 kW
* Spark Ignited
* 2.7 g/kW-hr NOx
* Operating in LA
* UP & BNSF
**GAS RAIL USA**

* Cooperative Industry Research Project
* Coordinated by SwRI
* Initiated in 1993
* Objective:
  » Develop Gas Engine Technology for a Low NOₓ Passenger Locomotive
  » Apply Technology to Revenue Service Demonstration in Los Angeles, California

**GAS RAIL USA Participants**

* Southwest Research Institute
* U.S. Department of Energy
* South Coast Air Quality Management District
* Southern California Regional Rail Authority
* California Air Resources Board
* Union Pacific Railroad
* Electro-Motive Division of General Motors
* Southern California Gas
* Gas Research Institute
* Amoco Petroleum Products
GAS RAIL ENGINE DEVELOPMENT

* 49.2 m³ (13,000 gal) LNG Storage Tank
* Cryogenic Pumps to 41.4 MPa (6,000 psi)
* Vaporizers
* 725 kg/hr Methane

1992 - EMD 710 Engines Installed to Support Gas Rail USA

EMD 1-710 single-cylinder test engine

EMD 16-710G3 test engine
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CARB Fuel Effects Study

* Began August 1998
* Test 4 fuels in a total of 6 locomotives
  » CARB diesel vs. on-hwy Federal diesel vs. two nonroad diesels
  » GE C44-9 (UP)
  » EMD SD70MAC (BNSF)
* Participant List:
  » CARB
  » UP
  » BNSF
  » AAR
  » EMD & GE locomotive support
CARB - Unregulated Emissions

* Selected unregulated emissions were also measured
  » Volatile Organic Fraction (VOF) of total particulate
  » Sulfates
  » Benzene
  » 1,3-Butadiene
  » Formaldehyde
  » Acetaldehyde
  » PAH (both gas phase and PM phase)
  » Metal Particulate
  » Soluble Organic Fraction (SOF)

SwRI Locomotive Emissions Test Center

* Established in 1992 for the AAR
* To date, over 50 locomotives tested
* Projects for EPA, CARB, CaDOT, DOE, AAR, RR’s, and OEM’s
  » Most of this data is in the public domain
## TABLE 1. AVERAGE CHANGE IN REGULATED LOCOMOTIVE EXHAUST EMISSIONS BETWEEN TEST FUELS

<table>
<thead>
<tr>
<th>FUEL CHANGE</th>
<th>Percent change in Average Line-Haul Composite Emissions $^a$</th>
<th>HC</th>
<th>CO</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMD SD70MAC</td>
<td>CARB vs. On-Hwy</td>
<td>+ 1 %</td>
<td>+ 7 %</td>
<td>- 4 %</td>
<td>- 3 %</td>
</tr>
<tr>
<td></td>
<td>CARB vs High Sulfur $^b$</td>
<td>+ 3 %</td>
<td>+ 8 %</td>
<td>- 6 %</td>
<td>- 16 %</td>
</tr>
<tr>
<td></td>
<td>On-Hwy vs High Sulfur $^b$</td>
<td>+ 1 %</td>
<td>+ 1 %</td>
<td>- 3 %</td>
<td>- 13 %</td>
</tr>
<tr>
<td>GE DASH9-44CW</td>
<td>CARB vs On-Hwy</td>
<td>- 4 %</td>
<td>- 1 %</td>
<td>- 3 %</td>
<td>- 3 %</td>
</tr>
<tr>
<td></td>
<td>CARB vs High Sulfur $^b$</td>
<td>+ 2 %</td>
<td>- 2 %</td>
<td>- 7 %</td>
<td>- 38 %</td>
</tr>
<tr>
<td></td>
<td>On-Hwy vs High Sulfur $^b$</td>
<td>+ 6 %</td>
<td>- 2 %</td>
<td>- 4 %</td>
<td>- 38 %</td>
</tr>
<tr>
<td></td>
<td>CARB vs 0.3% Sulfur $^c$</td>
<td>+ 1 %</td>
<td>- 3 %</td>
<td>- 5 %</td>
<td>- 27 %</td>
</tr>
<tr>
<td></td>
<td>On-Hwy vs 0.3% Sulfur $^c$</td>
<td>+ 4 %</td>
<td>- 2 %</td>
<td>- 2 %</td>
<td>- 25 %</td>
</tr>
<tr>
<td></td>
<td>0.3% Sulfur vs High Sulfur $^b$</td>
<td>+ 2 %</td>
<td>0 %</td>
<td>- 2 %</td>
<td>- 17 %</td>
</tr>
</tbody>
</table>

Notes:
- $^a$: EPA Line-Haul duty cycle weighted emissions.
- $^b$: 4,670 ppm sulfur nonroad fuel, EM-2664-F
- $^c$: 0.3% sulfur fuel = 3,190 ppm sulfur, EM-2708-F
DOE-NREL Biodiesel Study

* U.S. DOE (National Renewable Energy Lab) Project at SwRI to test Biodiesel fuel in a locomotive
  » Diesel baseline, CARB diesel baseline, B20, C20
  » Triplicate EPA tests on each fuel
  » NREL Contact is Dr. Shaine Tyson 303-275-4616

* Current Status - Recently completed testing
  » CSXT No. 2629
  » EMD GP38-2
  » EMD 16-645-E (roots-blown)

* Final report soon

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**Lubricating Oil Issues**

* Retarded fuel injection timing will lead to increased soot loading, and higher viscosity
* New oil formulations likely to be necessary
* Lube suppliers working to address engine oil needs for Tier 0, 1, and 2 locomotives
* Lessons learned from truck engine experiences
* Need access to Tier 2 engines NOW to be assess issues

**Lube Oil Contribution to PM**

* At 50 ppm fuel sulfur, the lubricating oil contribution to PM sulfate is about the same as that from fuel
* Low oil consumption cylinder kits
* Lower sulfur lubricating oil base stocks
* Metal additive effects on PM size and number
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Diesel Technology Options

<table>
<thead>
<tr>
<th>FJ SYSTEM</th>
<th>COMBUSTION</th>
<th>INDUCTION</th>
<th>FUEL</th>
<th>AFTERTREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH M. PRESS., SMALL HOLE NOZZLE, LOW BAC VOLUME INJ, INJECTOR SHAPE TIMING DEVIATION ELECTRONIC CONTROL, PEAK GATING GAS FLEXIBLE TIMING</td>
<td>REENTRANT BOWLS HIGHER TOP RING CONCENTRATED BOWLS BLOWER, INJECTOR, INJECTOR POLARIZATION, COMBUSTION IMPELLER RINGS HTI COMPR, RAPID HOMOGENEOUS COMPRESSION (HCO)</td>
<td>COLD COMBUSTION AIR INJECTION BETTER TURBO MATCH NEW OSCILLATORY EMBL, RATIO MATCH WITH FIXED CAMSHAFT, EXHAUST RECIRC, COOLED EGR COOLED/COATED EGR TIMES PORT EGR FAST AIR BOOST</td>
<td>LOW SULFUR SULFUR-FREE ARO/DEER DME NG LPG EMULSION BLEND/E85</td>
<td>OXIDATION CATALYSTS LEAN NOx CATALYSTS LEAN NOx CATALYSTS WITH REDUCANT PLASMA-ACTIVATED LEAN NOx CATALYSTS SELECTIVE CATALYTIC REDUCTION (NH3, UREA) THERMALLY-ASSISTED TRAP CATALYSTS - ASSIGNED TRAP ADDITIVE-ASSISTED TRAP OFF-LINE REGENERATED TRAP</td>
</tr>
</tbody>
</table>
Technology Options

* Water emulsions
  » PuriNOx
  » A-55
  » Auqazole
  » others?
* Idle shutdown systems
  » Automatic shutdown & restart
  » Kim Hotstart APU
  » Others
* Lubricant issues
* Fuel Cells
* DB Energy recovery systems

Diesel Fuel Summary

* Daily use fuel not regulated by EPA (...yet)
* Emissions test fuel is specified by EPA, with a sulfur content of 2,000 to 4,000 ppm
* Expect future emphasis on reducing fuel sulfur level to follow on-highway regulations
* Current US on-highway fuel sulfur 500 ppm max.
* 2007 = 15 ppm max for on-highway