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LOCOMOTIVE EXHAUST EMISSIONS FROM TAR-SANDS-DERIVED FUEL

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Summary

Tests performed by Southwest Research Institute (SwRI) on low cetane diesel fuel derived from tar sands have demonstrated statistically significant reductions in particulate matter (PM) and in oxides of nitrogen (NO_x) in both a General Electric (GE) and a General Motors Electro-Motive Division (EMD) engine. This finding is particularly important in light of the opinion of some regulatory agencies that fuels with lower cetane numbers will produce higher emissions. While tar sands fuel is not commercially available in the U. S., it is used extensively in railroad applications in Western Canada. Using this fuel results in a slight increase in fuel consumption, but the lower price of this fuel has resulted in a net reduction in fuel cost with no adverse maintenance effects.

High-cetane fuel, low-sulfur fuel, and low-aromatic fuel have previously been found to reduce emissions of either PM or NO_x in some smaller diesel engines. Tests previously conducted by AAR/SwRI failed to confirm anything more than a marginal effect in EMD and GE locomotive-type engines, and the cost of such fuels could be considerably higher.

This test was part of a series of tests on locomotive diesel engines conducted by AAR/SwRI to determine the effects on gaseous and particulate emissions of different fuels and lubricants and of changes in engine configuration. The testing program supports the rail industry in dealing with both state and federal regulators.

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INTRODUCTION AND CONCLUSIONS

The U. S. Congress has mandated that the Environmental Protection Agency (EPA) set emissions standards for most air pollution sources. Each state must develop plans for complying with these standards.

Federal emissions standards for new locomotive engines must be developed by November 1995. EPA currently plans to establish emissions limits for engines manufactured starting in January, 2000 as well as most of the pre-2000 engines in the fleet. The latter engines will have to be retrofitted during regular overhauls.

AAR and SwRI have an ongoing program to evaluate alternative fuels and proposed engine modifications at their jointly-owned diesel engine laboratory at San Antonio, Texas. The principal engines used in this program are 12-cylinder, turbocharged EMD 645E3B and GE 7FDL engines. These engines have been updating to current in-service configurations. The laboratory has been updated by installing complete gaseous emissions and particulates measuring equipment.

During 1992 tests were run with fuel produced from tar sands. This fuel, which is used extensively by railroads in Western Canada, is of interest because it has a low aromatic content and a lower cetane number and sulfur content than any fuel previously tested.

The test fuel resulted in a statistically significant PM reduction in both the GE and the EMD engines. It also resulted in a smaller but statistically significant reduction in NO_x in both engines. These reductions were achieved in spite of the much lower cetane number of the test fuel, which tends to refute the opinion held by some regulatory agencies that fuels with lower cetane numbers produce higher emissions. SO_2 was, of course, reduced in both engines in direct proportion to the reduction in sulfur in the fuel.

Since this fuel is not commercially available in the U. S., no statement can be made about its cost in the U. S. Its use would cause a slight increase in fuel consumption, resulting from its lower specific gravity.

EFFECT OF FUEL SPECIFICATION ON EMISSIONS

In the past, fuel sulfur content, aromatic content, and cetane number were all thought to affect engine emissions. Lower sulfur content results in lower sulfur dioxide (SO_2) emissions and was thought to contribute to reducing PM. Lower aromatic content often led to reduced PM in smaller engines. Higher cetane numbers produce better combustion in small, high-speed, diesel engines and were thought to promote selectively lowered emissions as a result. Consequently, one of the options being considered by California is requiring the use of low-sulfur, low-aromatic, high-cetane fuel.

Tests completed in the AAR/SwRI facility in 1991 compared three alternative fuels to standard diesel fuel. They were (1) an ultra-low-sulfur fuel; (2) a low-aromatic, high-cetane, low-sulfur fuel; and (3) Chevron's reformulated low-sulfur fuel. The results of these tests were summarized in Research Digest TD 92-013. These tests did not show any clear effect on emissions other than SO_2.

TAR-SANDS FUEL

A significant amount of locomotive fuel now being used in Western Canada is produced from tar sands. This fuel is of interest because it has a low aromatic content and a lower sulfur content and cetane number than any of the fuels previously tested. This type of fuel was tested at SwRI in both the EMD and GE test engines to evaluate its effect on engine emissions. Table 1 contains the specifications of the base and test fuels. The base fuel was representative of a regular number 2 diesel fuel oil.

Measurements were taken for PM, NO_x, hydrocarbons (HC), and carbon monoxide (CO). SO_2 was not measured but can be readily calculated, since it is directly proportional to the sulfur content.

The emission values in Table 2 are based on at least three readings at each of three throttle positions (idle, notch 5, and notch 8) which are then normalized for a typical engine duty cycle. These values are presented as ranges with 95% confidence limits.

TABLE 1. Diesel Fuel Analysis

	Fuel Description	
	Base	Tar Sands
API Gravity @60°F	34.5	36.9
Specific Gravity	0.852	0.840
Viscosity @40°C(cSt)	2.88	1.91
Cetane Number	48.9	40.0
Heat of Combustion (Btu/lb):		
Gross	19,500	19,500
Net	18,300	18,300
Sulfur (% mass)	0.250	0.007
Carbon (% mass)	86.6	86.6
Hydrogen (% mass)	13.2	12.8
Hydrocarbon Type (%volume)		
Aromatics	31.2	23.7
Olefins	2.3	1.8
Saturates	66.5	74.5
Distillation temp (°C)		
10% Recovery	434	386
50% Recovery	522	452
90% Recovery	612	533

The cycle-weighted average HC and CO for both engines are within test-to-test repeatability and showed no changes with tar-sands fuel. For both engines, the cycle-weighted average NO_x decreased significantly; the 95% confidence interval for the difference in the average NO_x emissions ranged from -1.26 to -0.10 g/bhp-hr for the EMD engine and from -1.53 to -0.28 g/bhp-hr for the GE engine. Similarly, for both engines the cycle-weighted average PM (CO_2-based) decreased significantly with tar-sands fuel; the 95% confidence interval for the difference in the average PM emissions ranged from -0.076 to -0.046 g/bhp-hr for the EMD engine and from -0.101 to -0.064 g/bhp-hr for the GE engine.

Some readers may desire to represent this difference as a percentage of the baseline average. Expressed in this fashion, the percent difference is obtained as follows:

% difference= [(Tar-sands - Baseline)/(Baseline)] X 100%

Adding 95% confidence bounds is not a simple task, because the percent difference represents a ratio of two variables rather than a single variable. The statistical procedure to construct such intervals yields only an approximate solution. These intervals, presented in Table 3, are approximate 84% confidence intervals.

TABLE 2. Brake-Specific Engine Emissions for Base and Tar-Sands Fuels

		95% Confidence Range Brake-Specific Emissions, g/bhp-hr			
Engine	Fuel	PM	NO_x	HC	CO
EMD 645E3B	Base	.206 to .230	12.27 to 13.07	.295 to .311	.706 to .833
	Tar-Sand	.146 to .167	11.62 to 12.37	.301 to .319	.798 to .883
	DIFFERENCE	-.076 to -.046*	-1.26 to -.10*	-.010 to .007	-.001 to .143
GE 7FDL	Base	.218 to .248	12.51 to 13.41	.272 to .330	2.407 to 2.679
	Tar-Sand	.137 to .163	11.55 to 12.56	.283 to .316	2.300 to 2.611
	DIFFERENCE	-.101 to -.064*	-1.53 to -.28*	-.033 to .030	-.279 to .104

*Difference is statistically significant at the 5% level.

TABLE 3. Approximate Confidence Intervals for % Reductions in NO_x and PM with Tar-Sands Versus 2-D Fuel

Brake-Specific Emissions Differences
(g/bhp-hr)

Engine	NO_x	PM
EMD	-8.37 to -2.33	-30.23 to -26.06
GE	-8.49 to -5.46	-44.02 to -26.85

The NO_x difference ranges from -8.37% to -2.33% for the EMD engine and from -8.49% to -5.46% for the GE engine (e.g., 2.33% to 8.37% lower NOx in the EMD engine with the tar-sands fuel.) The PM difference ranges from -44.47% to -33.93% for the GE engine and from -30.23% to -26.06% for the EMD engine.

Note that the reductions in PM and NO_x were achieved in spite of the lower cetane number of the test fuel. This indicates that higher cetane number by itself is not a good predictor of improved engine emissions.

The reader should keep in mind when reviewing the results in Table 2 that emissions readings can vary from one engine to another of the same type and can even vary in the same engine, depending on its condition.

The lower specific gravity of the tar-sands fuel results in a fuel consumption increase of 1.4%.

Although this fuel is not commercially available in the U. S., it is available in Western Canada at a per-gallon price which is 5-10% below the price of regular No. 2-D fuel. (This price level, however, may be influenced by a unique market condition.) Despite the small increase in fuel consumption, using this fuel in Western Canada has resulted in reduced fuel cost with no adverse maintenance effects.

Note: Contact G. Richard Cataldi at (202) 639-2261 with questions or comments about this document.

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