TECHNOLOGY DIGEST
Timely Technology Transfer

"Locomotive Exhaust Emissions: Effects of High-Cetane, Low-Sulfur, Low-Aromatic Fuels"

by G. Richard Cataldi and
Gary W. Widell

TD 92-013

__*Summary*__

The Association of American Railroads (AAR) and Southwest Research Institute (SwRI) are conducting a series of tests on locomotive diesel engines 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.

High-cetane fuel, low-sulfur fuel, and low-aromatic fuel have previously been found to reduce emissions of either particulate matter (PM) or oxides of nitrogen (NO_x) in some smaller diesel engines. Their emissions impact on General Motors Electro-Motive Division (EMD) and General Electric (GE) locomotive-type engines was measured at SwRI.

The testing performed to date indicates that the effectiveness of alternative fuel specifications in reducing either PM or NO_x is marginal at best. Moreover, the cost of such fuels may be considerably higher than of standard diesel fuel.

Association of American Railroads
Research and Test Department

September 1992

INTRODUCTION AND CONCLUSIONS

The California Air Resources Board (CARB) is studying several fuel and engine retrofit options for locomotive engines in connection with the development of locomotive exhaust emissions standards that would apply to the current fleet of locomotives. One of the options being considered by CARB is requiring the use of low-sulfur, low-aromatic, high-cetane fuel.

In order to evaluate the effects of potential new reduced emissions requirements and strategies, AAR and SwRI enhanced their jointly owned diesel engine laboratory at San Antonio, Texas, by adding a complete gaseous emissions and particulates measurement facility. The principal engines in this facility are 12-cylinder, medium-speed, turbocharged EMD 645E3B and GE 7FDL engines which their manufacturers assisted in updating to more current in-service configurations for these tests. The test program completed in 1991 in this facility included comparing three alternative fuels to standard diesel fuel, i.e., an ultra-low-sulfur fuel in 1989; a low-aromatic, high-cetane, low-sulfur fuel in 1990; and a reformulated low-sulfur fuel in 1991. The properties of the baseline fuels and the test fuels are presented in Table 1.

Fuel sulfur content, aromatic content, and cetane number are all thought to affect engine emissions in some way. Lower sulfur content results in lower sulfur dioxide (SO_2) emissions and is thought to contribute to reducing particulate matter (PM). Lower aromatic content often leads to reduced PM in smaller engines. Higher cetane numbers produce better combustion in small, high-speed, diesel engines and are thought to lower some emissions as a result.

The series of tests described below was performed to evaluate the effect of these three fuel variables on engine emissions. Table 1 contains the specifications of the fuels tested. Measurements were taken for PM, NO_x, hydrocarbons (HC), and carbon monoxide (CO). SO_2 was not measured but can be calculated, since it is directly proportional to the amount of sulfur in the fuel. While fuel properties may affect engine emissions levels, the fuels tested so far did not show any clear improvement in emissions other than SO_2. If the railroads are required to change their fuel specifications, there may be a penalty in both unit cost and fuel consumption, with no significant reduction in the emission of NO_x and PM.

FUEL CHARACTERISTICS

Number 2 diesel oil usually contains 25 to 35 percent aromatic compounds by weight. Aromatics tend to contribute to the formation of particulate matter in the exhaust and are thought to be carcinogenic. On some diesel engines, fuels with lower aromatic content than No.2-D produce lower oxides of nitrogen in the exhaust.

Cetane number is a measure of a fuel's ability to ignite under compression in a diesel engine. The higher the cetane number (content), the better the fuel's combustibility under compression. No.2-D has a minimum cetane number of 40 (pure cetane is 100). Previous AAR-SwRI studies have shown that locomotive diesel engines can operate effectively on fuels with a minimum cetane number of 32 (AAR Report R-684). Small, high-speed diesel engines sometimes produce lower NO_x with fuels that have cetane numbers in the high 40s or low 50s.

APPROACH

Each emission value presented is based on the averages of 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 in Table 2. In each case, statistical tests were performed to determine whether the differences between the base and test cases were statistically significant.

Table 1

DIESEL FUEL ANALYSIS						
	Fuel Description					
	1989 Tests		1990 Tests		1991 Tests	
	Base	Ultra-Low Sulfur	Base	Low Aromatic High Cetane, Low Sulfur	Base	Chevron Reformulated Low Sulfur
API Gravity @60°F	31.0	30.6	32.0	41.9	34.5	34.9
Specific Gravity	0.871	0.873	0.865	0.816	0.852	0.850
Viscosity @40°C (Cst)	3.16	3.55*	3.33	2.74	2.88	3.15
Cetane Number	44.8	42.8	44.2	54.5	48.9	49.9
Heat of Combustion (Btu/lb):						
Gross	19,300	19,500	19,400	19,900	19,500	19,500
Net	18,200	18,300	18,200	18,600	18,300	18,300
Sulfur (% by mass)	0.330	0.010	0.290	0.043	0.250	0.027
Carbon (% by mass)	87.3	87.0	87.3	85.7	86.6	86.6
Hydrogen (% by mass)	12.2	12.6	12.2	14.2	13.2	13.2
Hydrocarbon Type (% by volume):						
Aromatics	38.8	29.8	30.8	15.6	31.2	30.1
Olefins	1.9	2.9	5.1	4.0	2.3	0.0
Saturates	59.3	67.3	64.1	80.4	66.5	69.9
Distillation temperature (°C):						
10% Recovery	244	242	237	216	223	224
50% Recovery	278	271	280	263	272	272
90% Recovery	329	309	329	311	322	322

Table 2

BRAKE-SPECIFIC ENGINE EMISSIONS FOR VARIOUS FUELS										
			Fuel Characteristics			Average Brake-Specific				Fuel Consumption Penalty
Engine	Test Year	Fuel	Sulfur (Mass%)	Aromatics (vol%)	Cetane Number	PM	NO_x	HC	CO	%
EMD 645E3B	1989	Base	0.330	38.8	44.8	0.28	11.7	0.33	0.80	-
		Test	0.010	29.8	42.8	0.22*	11.0	0.36	0.97*	(1.0)
	1990	Base	0.290	30.8	44.2	0.15	10.5	0.29	0.81	-
		Test	0.043	15.6	54.5	0.17	10.4	0.33	0.83	3.5
	1991	Base	0.25	31.2	48.9	0.22	10.9	0.34	1.01	-
		Test	0.027	30.1	49.9	0.19	10.2*	0.32	0.96	0.0
GE 7FDL	1989	Base	0.330	38.8	44.8	0.26	10.8	0.60	2.23	-
		Test	0.010	29.8	42.8	0.26	10.8	0.60	2.12	(1.0)
	1990	Base	0.290	30.8	44.2	0.19	11.2	0.42	1.98	-
		Test	0.043	15.6	54.5	0.18	9.9*	0.36	1.87	3.5
	1991	Base	0.25	31.2	48.9	0.28	12.2	0.38	1.73	-
		Test	0.027	30.1	49.9	0.17	11.8	0.37	1.69	0.0

* Significant at the .05 level.

RESULTS

In 1989 an ultra-low-sulfur fuel was compared with a typical diesel fuel (1989 Base in Table 1) in the two 12-cylinder engines in the San Antonio laboratory. There was a small, statistically significant reduction in the average grams per brake-horsepower-hour of particulates with the ultra-low-sulfur fuel in the EMD engine (.28 vs .22), but no significant change in particulates in the GE engine. There were no significant changes in NO_x in either engine with this fuel.

Using slightly different measuring procedures in 1990, a low-sulfur fuel which was also low in aromatics and had a high-cetane number was compared with another typical diesel fuel (1990 Base in Table 1) in these same engines. There were no significant differences in any of the emissions with this fuel, compared with the base fuel, for the EMD engine. There was a small, statistically significant reduction in the average grams per brake-horsepower-hour of NO_x in the GE engine (11.2 vs 9.9).

In 1991 a reformulated low-sulfur fuel supplied by Chevron was compared with a typical diesel fuel (1991 Base in Table 1) in the two 12-cylinder engines in the San Antonio laboratory. The only significant difference in the averages of these observations is the small reduction in NO_x for the EMD engine (10.9 vs 10.2 grams per brake-horsepower-hour). [Note that although there was about a 40 percent reduction in average PM for the GE engine with this fuel (.28 vs .17g/bhp-hr), this reduction is not statistically significant, due to the variability in the individual observations.]

The results of the six fuel tests on each of the two engines are shown in Table 2. The small differences in these average measured emissions are most often the result of such factors as instrumentation error and normal variability in engine performance rather than fuel-related emissions changes. It should be kept in mind when reviewing the results in Table 2 that these average values are based on a small number of tests on only one EMD and one GE engine. There can be substantial variability in emissions among engines of the same design, within the same engine from one test to the next, or within the same engine over time.

FUEL COSTS

The low-aromatic, high-cetane, low-sulfur fuel (1990 test fuel) is lighter than the other fuels and results in an increase in fuel consumption of more than 3%. This fuel is not now commercially available, so the premium over the cost of regular No. 2-D fuel is unknown. The cost premium for fuel with less than 10% aromatics, however, has been estimated to be as great as $0.25 per gallon. A regular No. 2-D fuel that has less than 0.05% sulfur (the EPA highway fuel specification starting in 1993), such as the Chevron reformulated fuel, may cost $0.01 - 0.02 extra per gallon. Sulfur provides lubrication of fuel injectors; therefore, injector life may be shortened when using low-sulfur fuel.

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