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EXPERIMENTS WITH NOVEL FUELS FOR DIESEL ENGINES

By

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W. F. Marshall¹

ABSTRACT

Engine tests were conducted with two fuels that would be considered as novel for use in diesel engines. The fuels--methanol and a water/diesel fuel emulsion--were used in this study because of their potential for reductions in exhaust emissions. The test results showed that these fuels yield no advantages over standard diesel fuel with respect to emissions of unburned hydrocarbons and oxides of nitrogen. Although smoke and carbon monoxide emissions were reduced with the use of the water/fuel emulsion, the same effect could also have been achieved via engine adjustment.

INTRODUCTION

Interest in the use of alternative or novel fuels for engines is based on several considerations. Among these are:

1. Potential substitution for standard fuels if their supply becomes limited
2. Increased fuel or energy economy
3. Decreased emissions

For engines operating in underground mines, the primary benefit from use of alternative fuels could be a reduction in toxic emissions. Two possible alternate fuels that can be, or are, produced in quantities sufficient for mining applications and which may have the potential for reduced emissions are methanol and water-diesel fuel emulsions.

An analysis of methanol's potential for emissions reduction indicates that there should be no emissions of polynuclear aromatics (PNA), high molecular weight hydrocarbons (HC), and sulfur compounds and greatly reduced levels of particulates. The influence of water-fuel emulsions is not so easily formulated. However, if the water tends to reduce peak combustion temperature, emissions of oxides of nitrogen (NO_x) should be reduced. This toxicant is, for many engines, the controlling pollutant with respect to ventilation air requirements for dilution of the exhaust to safe working levels. Thus, any reduction in NO_x emissions rate could reduce the ventilation requirement, or, at a given ventilation rate, lessen the likelihood of ambient NO_x levels reaching unsafe or undesirable levels.

¹Mechanical engineer.

Because of the potential for use of these fuels, the Department of Energy's Bartlesville (Okla.) Energy Research Center (BERC) undertook an experimental investigation into the fuel's effect on exhaust emissions. This work was conducted as part of BERC's ongoing cooperative program with the Bureau of Mines--an experimental investigation of reduction of emissions from engines operated in underground mines.

EXPERIMENTAL PROCEDURES

Two different engines were used in this investigation--descriptions are given in table 1. The engine selection for both phases was based on compatibility of the novel fuels with the fuel delivery/metering systems. The specifications for the base fuel (used in both phases of the work) are given in table 2.

The engines were mounted on test stands and coupled to eddy-current dynamometers. Exhaust composition was determined with continuous analyzers for measurement of carbon monoxide (CO), carbon dioxide (CO₂), HC, and NO_x. The engines were operated over wide ranges in speed and load with base fuel and the test fuels. In the case of the methanol study, the maximum attainable power using the base fuel was limited to that attainable with methanol by resetting the fuel rack limit. (The heating value of methanol per unit volume is about 50 pct of that of diesel fuel.) It was found that the engine would not run on pure methanol and required an ignition improver (a hexyl nitrate). The level of the additive was gradually increased until the engine ran without significant knocking. This level corresponded to approximately 16 pct additive --84 pct methanol (by volume).

In the emulsified fuel tests the injection timing of the engine was systematically varied in an attempt to discern if there was any interactions between timing and fuels. The injection timing settings were:

Advanced.....6° Before top center (BTC) (end of injection)
Standard.....3° BTC
Retarded.....3° After top center

The emulsion was prepared from a mixture of the base fuel and water in a ratio of fuel/water = 80/20 (by weight). A proprietary mixture of emulsifying agents was added to the mixture, which was then emulsified with a high-speed stirrer. A single batch of the emulsion was used in these tests.

TABLE 1. - Engine description

Manufacturer	Displacement, CID	Features	Test fuel
Mitsubishi	330	4-Stroke cycle, precombustion chamber, individual pump/fuel injection system	Methanol
Detroit Diesel	284	2-Stroke cycle, direct-injection, unit injectors	Water/fuel emulsion

TABLE 2. - Fuel specifications

Gravity, °API.....	36
Distillation, °F:	
10 pct evaporated.....	386
50 " "	472
90 " "	568
Composition (FIA) ¹ , vol pct:	
Aromatics.....	31
Olefins.....	5
Saturates.....	64
Cetane index.....	44
Sulfur content, wt pct.....	0.15

¹Fluorescent indicator absorption, ASTM D1319.

After the conclusion of the engine tests, the emulsion was examined. It had the same appearance--milky white--as it had when it was originally prepared. At a later date (approximately 1 month) the mixture remained in a single phase--no discernable separation.

RESULTS AND DISCUSSION

Methanol

Results of the tests with methanol indicated marked increases in emission levels of CO, HC, and NO_x over the levels obtained using a No. 2-D fuel. A comparison of emission rates for the two fuels is shown in figure 1. Although nitric oxide (NO) emission rates were comparable for the two fuels, emission rates for nitrogen dioxide (NO_2) were much greater for the methanol case. The NO_2 fraction, which was on the order of 20 to 50 pct of the total NO_x , was presumably a decomposition product of the nitrate-based ignition improver. Levels of NO_2 in the exhaust from engines burning diesel fuel (without nitrate additives) are typically on the order of 10 pct of the total NO_x .

Using methanol, emissions of CO increased by a factor of 2 over the baseline case, and emissions of HC increased by a factor of roughly 2 to 10. The increased HC levels might be attributable to the following occurrences in the combustion chamber: vaporization, dilution to beyond the lean flammability limit, and expulsion (as methanol) in the exhaust stroke. Since the composition of the exhaust HC was not determined, this explanation is only a hypothesis.

The hydrocarbon data presented here are "as measured," that is, no response corrections were applied. The HC analyzer used in the experiments had about a 70 pct response factor for methanol--100 ppm methanol actual = 70 ppmC indicated. Thus, if the methanol was a major constituent of the unburned HC, the actual hydrocarbon emission rates were somewhat greater than those shown in figure 1.

FIGURE 1. - Emission Rates Versus Power Output with Methanol and No. 2-D Fuels: Mitsubishi Engine

Because the emission characteristics with methanol were unfavorable, further investigation was deemed unprofitable. Therefore, the study was terminated rather than extended into analysis of hydrocarbon compositional detail and determination of other emissions.

The results of this study should not be extrapolated to predict the consequences of utilizing methanol in other engine/fuel metering systems. For example, a system which incorporates pilot injection of diesel fuel (for ignition) could utilize methanol without the need for the ignition improver fuel additive which acts as a source of NO_x emissions.

Emulsified Fuel

Results of tests with emulsified fuel indicate that the fuel had only a minor effect on NO_x emissions, reduced peak emission rates of smoke and CO, and increased HC emissions. A summary of results is given in table 3. The effect on NO_x is shown in figure 2. The maximum influence (10 pct reduction) occurred with the injection timing advanced. The NO_x emission rates at the standard and retarded timing conditions were virtually unaffected.

Emissions of CO as a function of power are shown in figure 3. The level of CO increased at light load conditions, but was greatly reduced at full load. Smoke levels displayed virtually the same dependence on power and fuel. The same results (reduction in peak levels) could be accomplished with standard fuel by engine adjustment -- simply by "derating" or limiting the maximum fuel delivery rate.

Levels of unburned HC generally increased with use of emulsified fuel, particularly at light load conditions. (See figure 4.) No detailed analysis of the HC material was made. If the results had shown the use of emulsified fuel to be beneficial, a more detailed experimental investigation was to have been conducted. However, this was not the case, and the investigation was not extended into further experiments.

TABLE 3. - Summary of results

-- 13 Mode Cycle Averages--

Fuel	Injection timing	Bsfc, lb Diesel fuel hp-hr	bs Emissions, g/hp-hr		
			CO	HC	NO_x
No. 2-D	Advanced	0.448	3.5	0.9	17.3
	Standard	.450	5.3	.9	13.5
	Retarded	.468	4.2	1.1	7.2
Water/fuel emulsion	Advanced	0.443	2.4	1.3	15.4
	Standard	.451	2.8	1.3	15.2
	Retarded	.468	3.1	2.0	7.9

FIGURE 2. - Effect of Fuel on NO_x Emissions

FIGURE 3. - Effect of Fuel on CO Emissions

Emulsions might have some good features extraneous to engine operation (fire safety, for example), and, if this is deemed to be an important facet pertaining to safe operation of diesels underground, there will be need for better, more comprehensive investigation of composition of exhaust from engines using emulsified fuel.

An emulsion would probably have a higher flash point than the base fuel. Also, in the presence of a heat source, the temperature of the emulsified fuel might tend to remain lower because of the heat being dissipated in vaporizing the water. However, no experiments were conducted in this area in this investigation.

FIGURE 4. - Effect of Fuel on HC Emissions

SUMMARY AND CONCLUSIONS

1. The use of methanol as a diesel fuel yielded very poor exhaust emission characteristics. Emissions of CO, HC, and NO_x were substantially increased over levels when using a 2-D fuel. Because of its adverse influence on emissions and low flash point, methanol does not appear to be a feasible alternative to diesel fuel for engines operating in underground mines.

2. The use of an emulsified mixture of water-diesel fuel in a diesel engine had no beneficial effects on emissions of NO_x , caused slightly greater HC emissions, and reduced peak levels of CO and smoke. The reduction in CO and smoke levels, however, could also be achieved, quite easily, by engine adjustment (by limiting maximum fuel rate). Thus, there were no net benefits.