EMISSIONS SAMPLING OF COMBUSTION EFFLUENTS FROM A STATIONARY DIESEL BURNING A COAL DERIVED LIQUID FUEL

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Introduction

The purpose of this study was to evaluate the performance of a utility diesel generator when burning a middle distillate Exxon Donor Solvent (EDS) coal derived liquid fuel. While coal derived liquid fuels have been successfully fired in external combustion sources (1,2), their use in internal combustion sources is limited by 1) low octane number, 2) high distillation range 3) high nitrogen and sulfur content and 4) high aromatic content. These factors may influence both the engine performance and the emissions of particulates and gaseous products of combustion.

Technical Approach

For this program a Cooper LSV-16-GDT 16-cylinder, 4-stroke, turbocharged engine was used to evaluate various blends of EDS and a standard DF-2 fuel. The engine was owned and operated by a public utility company. Cooper Energy Services designed a test matrix for the evaluation of fuel blends at different engine operating conditions and supervised the actual engine test operations. Basically three operating parameters were varied: the fuel blend ratio as EDS/DF-2, the air manifold temperature (AMT) and the engine/speed load conditions as kilowatts (KW) of electrical power at rated speed. In addition a specially designed sampling system was used to evaluate extreme blend ratios and test engine modifications applied to only one of the 16 cylinders. Baseline tests on the DF-2 fuel were made at the various test conditions for comparative purposes.

Sampling for gaseous emissions was conducted at two locations of the engine exhaust. In one location a rake type probe with a heated sampling line was used to continuously withdraw samples of the exhaust gas before it entered the silencer. A special check-valve sampling probe was installed for the single cylinder exhaust gas monitoring. Provision for SO_2/SO_3 sampling was included in both sample lines. A schematic of this system is shown in Figure 1.

The sampling for SO_2/SO_3 was by a controlled condensation system based on an original design by Goksoyr and Ross in 1962, followed by a hydrogen peroxide impinger train. This system is now referred to as the Goksoyr-Ross train and methods for operation are documented by both the U.S. EPA and the APHA.

Sampling for particulates was by a standard EPA Method 5 probe and impinger train. The method was modified by adding NaOH to the second impinger to allow determination of chloride emissions. The Method 5 sampling was conducted at the outlet of the silencer using two perpendicular sampling ports and multiple point traverses.

For the program, replicate tests were conducted when feasible. Duplicate measurements were made of SO_2 (EPA Method 6 and on NDIR instrument) and of NO_x (EPA method 7 and chemiluminescence instrument). Analyses of particulate, SO_3/SO_2 and Cl were made onsite. All gas monitoring instruments were zeroed and spanned daily using certified span gases.

Test Results

Fuel Analyses. Prior to actual sampling the fuel blends were analyzed by Southwest Research Institute (SWRI) and reported in their report to EPRI on this project (3). The octane number of the fuel blends ranged from 49.6 for 100% DF-2 to 21.0 for 100% EDS. The higher heating values (HHV) ranged from 19,500 Btu/lb to 18,569 Btu/lb (for 100% EDS). The nitrogen and sulfur content were variable but reported by SWRI as 0.09 percent sulfur and 0.12 percent nitrogen. This sulfur content is lower and the nitrogen is higher than most conventional diesel fuels. The DF-2 sulfur content was also low at 0.15 percent. The H/C ratio of the EDS was somewhat lower than the DF-2 (approximately 0.11 compared to 0.16) indicating a higher degree of aromatic constituents.

Baseline Tests. Baseline diesel tests were conducted at constant rated speed (360 rpm) and four generating loads, No Load, 1800 KW, 2600 KW, and 3600 KW. All tests were conducted at 110 F AMT except for the 3600 KW condition which also included 150 F AMT and 95 F AMT tests.

The gaseous emissions were comparable to those reported in other tests of diesel generators burning No. 2 diesel fuel.[(4)] The O_2 ranged from 10.8 percent at 3600 KW to 18.2 percent at FSNL. As expected, the CO_2 increased with increasing load. The CO was slightly higher than expected, up to 195 ppm at 3600 KW, indicating less than optimum performance. The SO_2 concentrations were low, reflecting the low sulfur content of the fuel.

Gaseous Emissions from Blend Tests. Tests were conducted for the various blend ratios and load conditions. The results from the stack emissions measurements for the full engine tests are summarized in Table 1. This table provides averages for each engine load condition as measured at the baseline fuel condition and for the three blend ratios. As was observed in the baseline tests, the CO_2 increased with engine load while O_2 decreased. There was no observed effect of blend ratio on SO_2 emissions, although SO_2 did increase slightly with increasing load as would be expected. The NO_x, when corrected to 15 percent O_2 (dry), showed a significant increase as load was increased to 1800 KW and then a more gradual increase up to the maximum load of 3600 KW.

The results of gaseous monitoring for the blend tests at AMT of 95 F and 150 F were compared to the 110 AMT tests. The 3600 KW baseline emission tests for 95 F and 150 F AMT were comparable to the 110 F AMT tests. The gaseous emissions showed no significant changes between operating temperatures except that the corrected NO_x appeared to increase slightly at 110 F AMT compared to 95 F AMT but to decrease when the AMT was raised to 150 F.

Particulate Emissions from Blend Tests. The stack particulate emissions for the baseline and three blend ratios were measured. The effect of blend ratios on the particulate emission rate is shown graphically in Figure 2. In this representation the percent increase of the particulate emission rate over the baseline value for the various blend ratios is plotted for the two higher engine loads at 110 F AMT.

The effect of blend ratio on the particulate emissions is significant. The increase in the rate over baseline is approximately the same for the two conditions load at 110 F AMT. The increase over baseline is greater at 150 F AMT and less at 95 F AMT. In terms of actual emissions rate based on mass of particulate per heat input, the 50 percent blend at 2600 KW and 110 F AMT was lowest while the 66.7 percent at 3600 KW and 110 F AMT was the highest. A test of 75 percent blend at 3600 KW and 150 F AMT was observed to have a lower particulate emission rate than the reported highest value and similarly a baseline test of 3600 KW and 150 F AMT showed a 42 percent lower particulate emission rate than either the 95 F AMT or the 110 AMT baselines. This suggests that increasing the AMT may reduce the particulate emission rate.

Other Gaseous Emissions. Emissions samples for SO_3 and chlorides measurements were also included in this program. In total, 12 samples for SO_2/SO_3 measurement were obtained; 6 were in the stack location and 6 were in the single cylinder configuration. No SO_3 was detected in any of the samples by the standard titration with 0.02 N NaOH. In each of the tests for particulate emissions conducted in this program, an impinger sample was collected for Cl determination by AgCl gravimetric method. In all cases there was no precipitate formation indicating chlorides were less than the detectable limit.

Conclusions

The use of EDS/DF-2 fuel blends in utility diesels provides an acceptable alternative to conventional petroleum based fuel operation. A blend ratio of approximately 66.7 percent EDS and 33.3 percent DF-2 can be used without engine knocking at an AMT of 110°F. At an AMT of 150 °F this ratio can be extended to 75 percent EDS. The major impact of the use of EDS blends appears to be an increase in the particulate emissions rate. The effect of EDS/DF-2 blends on particulate emissions was significantly influenced by both blend ratio and engine load. Increasing one or ther other or both resulted in an increase in the particulate emissions, though an increase in AMT may reduce the particulate emissions rates. No information on particle size or morphology was obtained in this program.

The results of the exhaust stack measurements of gaseous emissions indicate that the use of EDS/DF-2 fuel blends under engine load conditions resulted in a moderate increase in CO emissions (25%) and a moderate decrease in THC emissions (26-31%) when compared to baseline (0%) tests. The EDS/DF-2 fuel blends all showed substantial increases in both CO and THC emissions at the no-load condition.

The emissions of NO_x from EDS blends are less than or equal to the baseline over all engine loads except for the maximum EDS/DF-2 blend where NO_x levels were slightly higher at lower loads. A 150 F AMT slightly increased the NO_x for baseline and the 66.7 percent blend at 3600 KW but lowered the 2600 KW concentration. The overall average percentage of NO_2 in the NO_x at baseline conditions was approximately 9 percent. Due to problems with the NO analyzer the effect of AMT and blend ratio on NO_2 could not be determined.

There was little correlation between blend ratios and SO_2 emissions, all of which were relatively low. Measurements of SO_3 and Cl were below the expected lower limits and thus the potential for corrosion should be minimal in the use of EDS/DF-2 blends.

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References

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TABLE 1

AVERAGE STACK GASEOUS EMISSIONS DATA SUMMARY FOR FULL ENGINE TESTS
(From Reference 5)

Load (KW)	CO_2 (percent)	CO (ppm)	O_2 (percent)	SO_2 (ppm)	NO (ppm)	NO_x (ppm)	THC (ppm)
		0 Percent Blend, AMT = 110 F					
FSNL	1.8	178	18.2	67	--*	388	206
1800	5.6	87	13.2	73	803	835	142
2600	6.2	93	12.0	72	833	915	153
3600	7.2	161	10.8	80		986	166
		25 Percent Blend, AMT = 110 F					
FSNL	1.8	345	18.5	54		516	273
1800	7.8	105	13.3	60	776	835	155
2600	6.6	105	12.0	58	--	895	160
3600	7.2	175	11.1	55	--	962	205
		50 Percent Blend, AMT = 110 F					
FSNL	1.9	725	18.3	56		601	390
1800	6.0	110	13.0	56	--	850	117
2600	6.7	124	12.0	64	--	878	120
3600	7.4	162	11.0	62	--	991	128
		66.7 Percent Blend, AMT = 110 F					
FSNL	1.8	1200	18.5	50		540	750
1800	6.1	110	12.9	59	974	1007	108
2600	6.9	116	11.8	61	--	1004	105
3600	7.3	170	11.2	62	--	917	122

*Indicates data deleted due to malfunction of instrument.

Note: NO and NO_x data are corrected to 15 percent O_2.

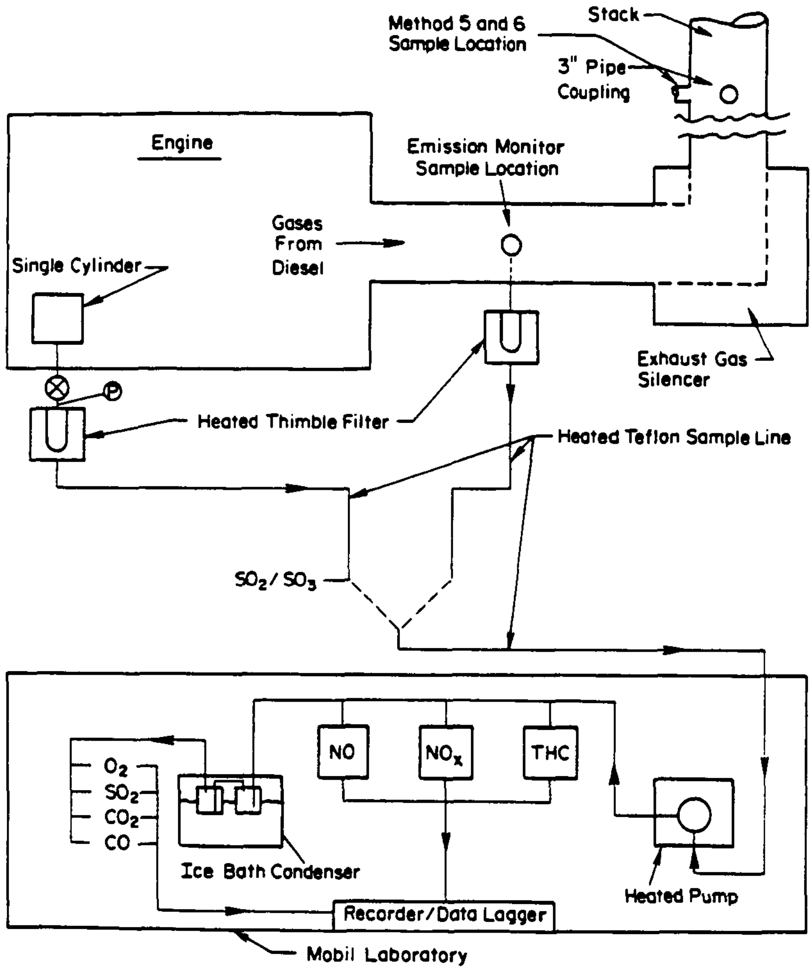

FIGURE 1. SCHEMATIC OF BATTELLE MONITORING AND SAMPLING EQUIPMENT

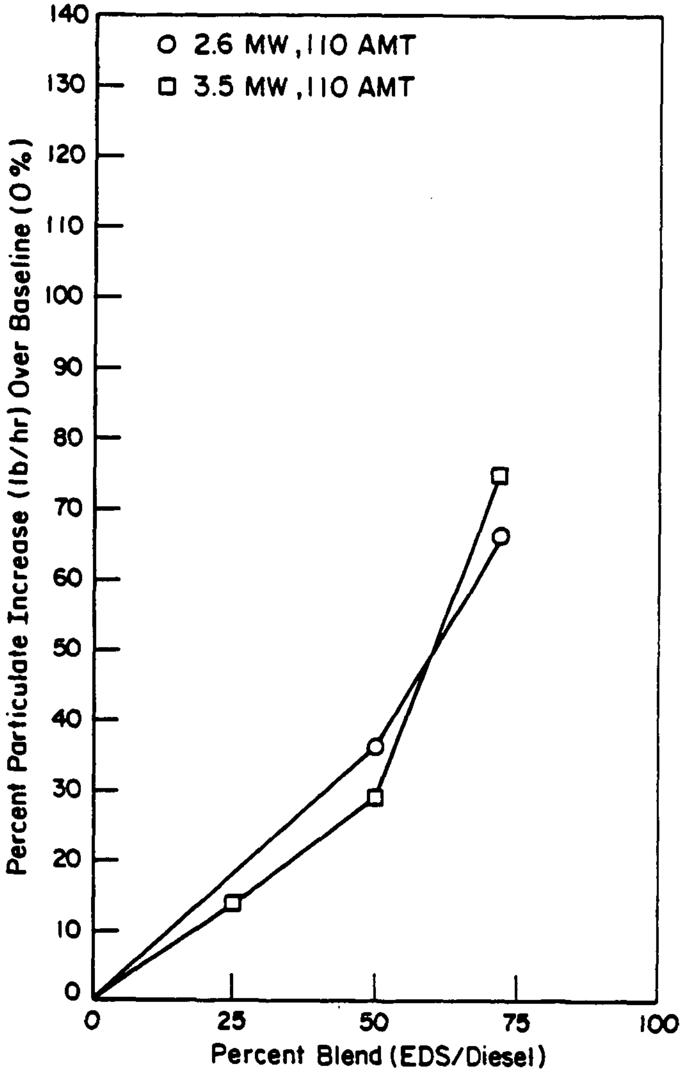

FIGURE 2. PARTICULATE MASS RATE INCREASE AS AFFECTED BY BLEND RATIO, ENGINE LOAD, AND AMT