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EFFECTS OF CETANE NUMBER AND CETANE IMPROVER ON EXHAUST EMISSIONS OF A SINGLE CYLINDER DI DIESEL ENGINE

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Introduction

A large number of studies have been conducted to investigate the effects of fuel properties on diesel engine emissions. Among the many fuel properties, cetane number is generally shown to be one of the more important factors which can influence engine exhaust emissions. The ignition quality of the fuel, however, can be affected by many physical and chemical properties. Therefore, it is expected that an engine can respond to the natural cetane number in a different way than it can to the cetane-improver-enhanced cetane number. This study investigate in detail the effect of cetane improver on the exhaust emissions of a single cylinder DI diesel engine.

The AVL 8-mode steady-state simulations of the EPA transient test are conducted on a Ricardo Proteus research engine using fuels of different cetane-improver-enhanced cetane numbers. Engine exhaust emissions of NOx, HC, CO and particulates are measured at two different injection timings. Using the information about injection event and cylinder pressure, the combustion process and heat release history can be obtained at all test modes. Based on these analysis, the effects of the cetane improver on the ignition delay and the duration of the premixed and the mixing controlled burning periods can be analysed which, in turn, help us understand the effect of the cetane improver on exhaust emissions.

Test Engine and Test Procedure

The test engine used in this program is a single-cylinder Ricardo Proteus research engine. Major engine configuration data are shown in Table 1. The performance and exhaust emission levels measured over the load and speed range are representative of current premium heavy duty diesel engines. The speed and the load of the test engine are controlled independently by a dynamometer and a fuel control system. Static fuel injection timing can be adjusted 30 crank angle degrees either side of TDC. To simulate a turbocharger, externally compressed air, controllable for temperature and pressure, is supplied to the engine. The engine oil temperature and coolant temperature are kept constant during the test.

A Kistler 6121 pressure transducer is mounted on the cylinder head to measure in-cylinder pressure traces. Engine crankshaft position is determined by an AVL 360C/720S optical crank angle encoder. The fuel injector is

Table 1 Test Engine Configuration

Engine Type	Ricardo Proteus (replicates one cylinder of Volvo TD123)
Bore	130.2 mm
Stroke	150.0 mm
Number of Cylinders	1
Displacement	1.997 liters
Combustion Chamber Type	Toroidal Bowl
Compression Ratio	17:1
Injection Type	Direct Injection
Fuel Injection Pump	Bosch PE6P 120A 320RS8011
Fuel Injection Nozzle	Bosch DLLA 152 P 285
Maximum Power Output	44.67 kW (60 bhp) @ 1900 rev/min

instrumented with a hall-effect needle lift sensor which together with a signal conditioning module provides indication of start and end of fuel injection.

Figure 1 shows the engine exhaust measurement system. A heated probe is mounted after the mixing tank to sample the gaseous emissions in the exhaust. The wet concentration of NO_x in the heated sample is measured continuously using a Beckman 955 chemiluminescent analyser and the wet concentration of the unburned hydrocarbons in the heated sample is measured using a Beckman 402 flame ionization analyser. The gaseous sample is then passed through a drying system, and the dry concentrations of CO, CO_2 and O_2 in the exhaust are measured using Beckman 865 and 864 nondispersive infrared analysers and a Beckman OM-11EA polarographic analyser, respectively.

A separate probe is used for particulate sampling, Fig. 1. The temperature of the probe is maintained above 190°C to prevent condensation. The exhaust sample is then diluted in a mini-dilution tunnel using filtered and dried air. The flowrate of the dilution air is regulated, so that the temperature in the dilution tunnel is maintained at 52°C. Two particulate matter sample lines are installed in the dilution tunnel. One is connected to a 47mm particulate filter and a dry test meter. The other line is connected to a Tapered-Element Oscillating Microbalance (TEOM) which measures the real-time particulate mass concentration. To determine the actual PM concentration in the engine exhaust, the concentration of CO_2 in the dilution tunnel is measured and compared to exhaust CO_2.

The AVL 8-mode simulation of the EPA transient test procedure was used in this study. The engine operating conditions and the weighting factors of this test procedure can be found in Ref.[1]. To ensure the measurement accuracy, all emission analysers were calibrated before and after each test run. Repeated tests were conducted to determine error margins. Throughout the whole study, a low sulphur diesel fuel was used to define the baseline performance of the test engine. Fuels having different cetane numbers were obtained by adding cetane improver ethylhexyl nitrate into the reference fuel. The resulting cetane numbers ranged from 44 to 64.

Test Results and Analysis

The total emissions are shown in Fig. 2. The NO_x emissions show a decrease of about 5% when the cetane number is increased from 44 to 64. The decrease in NO_x emissions occurred mainly in the cetane number range of 44 to 55. When the cetane number is further increased from 55 to 64, its effect on NO_x emissions becomes insignificant. The total particulate emissions are shown to increase about 15% when the cetane number is increased from 44 to 64. The increase in particulates also appears to be more profound in the range of 44 to 55 cetane number. The total CO emission shows a slight decreasing trend with the increase of cetane number, while the total hydrocarbons hardly show any change throughout the whole range of the cetane number.

Since the fuels tested in this study were blended from the same base fuel, all have almost the same properties. The only difference is the concentration of the ignition improver (maximum 1%) and thence the ignition quality. In general, it can be expected that a fuel with a higher cetane number will display a shorter ignition delay, therefore, a shorter premixed burning period. This leads to a smaller amount of fuel being consumed in the premixed burning and a larger quantity being involved in the mixing controlled burning. The formation of NO_x is affected by the amount of fuel being oxidized in the premixed burning, therefore, we observe this decrease in NO_x when cetane number is increased. On the other hand, a longer mixing controlled burning means a longer soot formation period. This leads to higher particulate emissions.

The total emissions are composite results from 8 different modes. It is helpful to examine individual mode and their contribution to the total emissions. Table 2 shows typical weighted emission rates at different modes. In calculating the values in the table, the emission rates at each mode were multiplied by the weighting factor of that mode. Therefore, the table indicates the relative importance of different modes to total emissions. For NO_x emissions, modes 7 and 8 are the heavy contributors. For particulate emissions, mode 4 is the heavy contributor. Modes 7 and 8 also contribute significantly to total PM emissions. For CO emissions, the heavy contributors are modes 4 and 5, whereas for hydrocarbon emissions, modes 5 and 6 contribute the most. In summary, for the Ricardo Proteus running an AVL 8-mode simulation, total NO_x emissions are generated mainly by high speed and high load operations; total particulate emissions come mainly from high load operations, especially at lower speed; total CO emissions are caused by both low speed/high load and high speed/low load operations; and the total hydrocarbon emissions can be attributed to low load operations.

Table 2 Emission Contributions at Different Modes

Speed (%)	0	11	21	32	100	95	95	89
Load (%)	0	25	63	84	18	40	69	95
Weighting Factor	35.01	6.34	2.91	3.34	8.40	10.45	10.21	7.34
Emission Rate (g/hr)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8
NOx	7.51	2.78	3.49	5.94	4.49	10.42	18.43	18.21
PM	0.02	0.01	0.04	0.32	0.11	0.09	0.20	0.23
CO	1.03	0.30	0.56	4.71	2.72	1.53	1.41	1.38
HC	0.73	0.16	0.14	0.10	1.14	1.14	0.65	0.50

From the cylinder pressure trace and the net heat release history, it can be observed that at all modes, the ignition delay is shortened when the cetane number is increased. For most of the modes, a reduction of less than 1 degree is observed in the ignition delay. At modes 4, 7 and 8, the reduction in the ignition delay is most apparent when the cetane number is increased from 44 to 55. The peak of the heat release in the premixed burning period is reduced significantly when the cetane number is increased from 44 to 55, indicating a reduced premixed burning. When the cetane number is increased further from 55 to 64, the reduction in premixed burning is not as obvious. This explains the trend we observed in NO_x and particulate emissions.

Conclusion

The results of this preliminary study can be summarized as follows:

- When the cetane number of the fuel is increased by adding a cetane improver from 44 to 64, the NO_x emissions decrease about 5%. This decrease occurs mainly in the 44 to 55 cetane number range.
- The particulate emissions tend to increase when the cetane number of the fuel is increased.
- The effects of cetane number on CO and unburned hydrocarbons are not significant.

Acknowledgment

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References

[1]. W. P. Cartellieri and P. L. Herzog, "Swirl Supported or Quiescent Combustion for 1990's Heavy-Duty DI Diesel Engines - An Analysis", SAE Paper 880342.

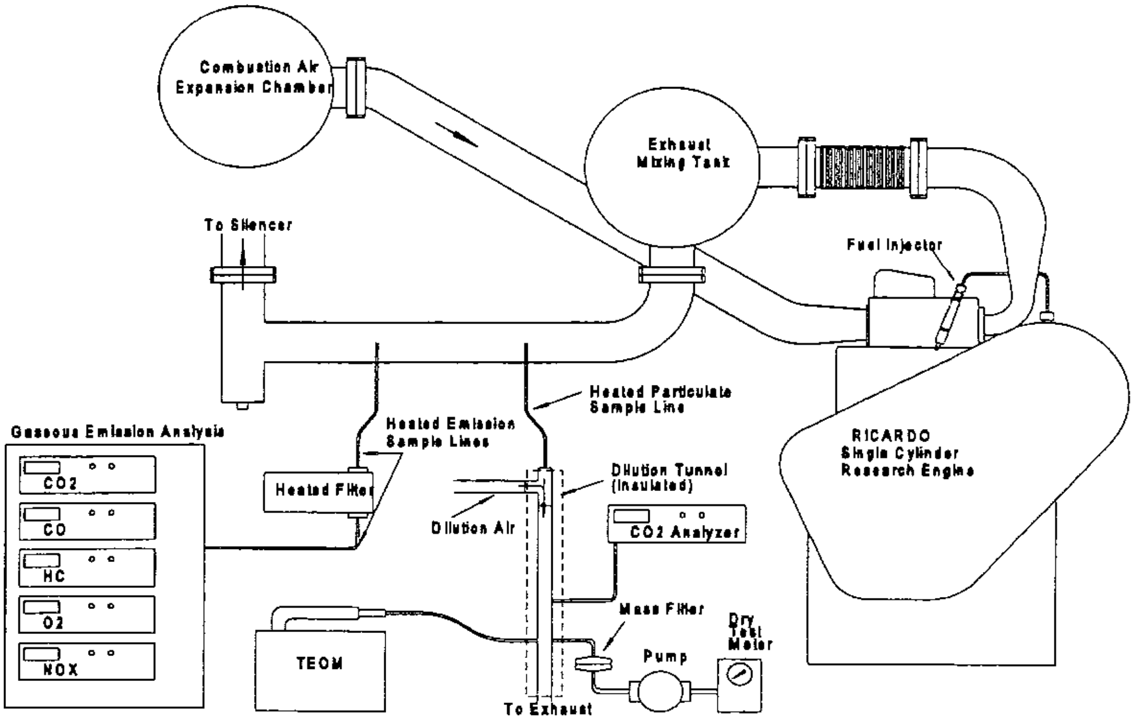

Figure 1 Engine and Emission Measurement System

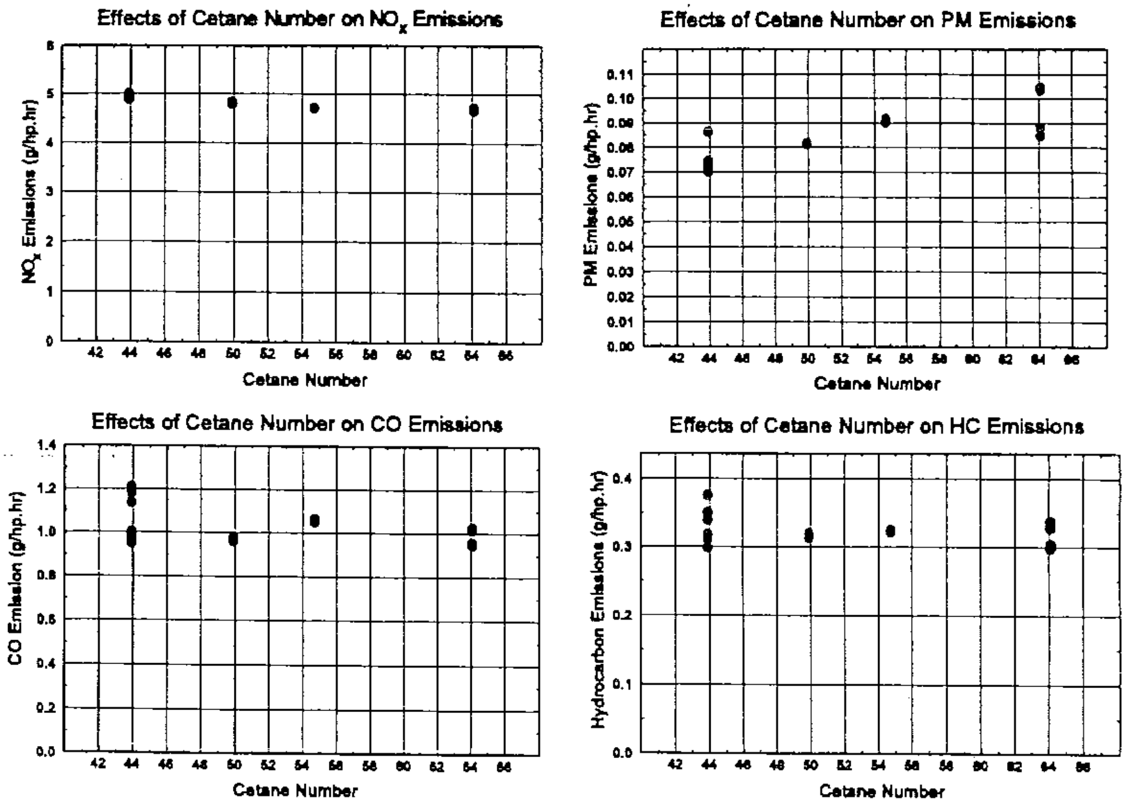

Figure 2 Effect of Cetane Number on Total Emissions, Static Timing: TDC

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