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EFFECTS OF CETANE NUMBER ON DIESEL EMISSIONS

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Introduction

Among the diesel fuel properties, cetane number has been shown to be one of the important factors which can influence engine exhaust emissions. The ignition quality of the fuel, however, can be affected by physical and chemical properties. In the petroleum industry, it is a common practice to use cetane improvers to enhance the cetane number of the commercial diesel fuel. Therefore, it is essential to quantify the effects of cetane number on exhaust emissions. It is also of special interest to compare the effects of nitrate type cetane improvers with other types, since the nitrate type improvers are generally believed to contribute to NOx emissions.

In this study, a number of fuels were studied in a single cylinder DI diesel engine to investigate the effects of cetane number on engine emissions. The single cylinder research engine used in this study incorporates the features of contemporary medium-to-heavy duty diesel engines. The engine experiments were run using the AVL 8-mode steady-state simulation of the EPA heavy duty transient test procedure. The experimental fuels used in this study included diesel fuels obtained from different sources with various natural cetane ratings as well as a number of fuels blended by adding two cetane improvers into three base fuels.

Experimental

The research engine used in this program was a single-cylinder Ricardo Proteus research engine. Major engine configuration data are shown in Table 1. Details of the engine setup, measurement system and engine test procedure can be found in Ref. 1.

Table 1 Research Engine Configuration

Engine Type	Ricardo Proteus (replicates one cylinder of Volvo TD123)
Bore	130.2 mm
Stroke	150.0 mm
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

The experimental fuels used in this study included diesel fuels obtained from different sources with various natural cetane ratings. The properties of these fuels are shown in Table 2. Three of the five base fuels were of conventional type. The other two were synthetic type (derived from tar sands). Among the three conventional type fuels, fuels Ref1 and Ref2 had total aromatic contents of about 25%, whereas fuel Ref3 had an aromatic content of about 5%. Of the two synthetic type of diesel fuels, one had aromatic content of about 30% and the other of about 10%.

Table 2 Properties of Base Fuels

FUEL ID	REF1	REF2	REF3	S30A	S10B
Source	Conventional	Conventional	Conventional	Synthetic	Synthetic
Density, kg/m^3	836.2	835	842	840.8	834.2
Viscosity @40°C, cSt	2.135	2.207	4.03	1.81	2.14
Cloud Point, °C	-22	-19	-6	-28	-27
Dist, D86, IBP, °C	178.5	172.9	175.5	170.5	158.5
T10, °C	205.6	198.9	244.8	185	183
T50, °C	245.5	255.9	297.8	222.5	244
T90, °C	306.1	311.4	333.8	324	317
EP, °C	343.3	336.7	352.6	347.5	344.5
Cetane In., D976-80	46.6	49.7	55.5	37.9	46.8
Cetane No. D613	43.9	46.2	55.4	36.5	43.4
Hot FIA Aromatics, %v.	24.2	23.4	4.7	27.8	10.6
Hot FIA Olefins, %v.	1.6	1.9	1.4	2.9	2
Hot FIA Saturates, %v.	74.2	74.7	93.9	69.3	87.4
Sulfur, ppm (mass)	287	351	9.2	84.7	2.4
Nitrogen, ppm (mass)	54.1	42.9	2.5	24.8	0.3
HPLC Aromatics, %m				32.1	12
HPLC MAH's, %m				29.6	10
HPLC DAH's, %m				1.9	1.5
HPLC PAH's, %m				0.6	0.5
GC/MS data					
Paraffins %m	29.2	35	24.9	22.2	21.3
Mono-Cycloparaffins %m	20.8	20.2	23.4	19.9	32.0
Di-Cycloparaffins %m	15.8	13.7	22.7	16.1	21.0
Poly-Cycloparaffins %m	8.8	8.2	24.6	11.2	13.3
Mono-Aromatics %m	20.5	16.6	3.6	26.4	9.3
Di-Aromatics %m	4.7	5.9	0.5	3.8	2.7
Poly-Aromatics %m	0.2	0.4	0	0.1	0.2

Throughout the study, fuel Ref2 was run frequently to check the engine performance shift. From the repeated data points, the repeatability of the engine experiments can be estimated. The standard deviations over the means of the emission data are shown in Table 3.

Table 3 Repeatability of Engine Experiments

Emissions	NOx	PM (filter)	CO	HC	Fuel Consumption
Repeatability % (Std. Dev./Mean)	0.9	4.3	2.5	7.2	0.4

Results and Discussion

To compare the effects of the nitrate type cetane improver to those containing no nitrogen, two different cetane improvers, one of nitrate type (2 ethyl hexyl nitrate) and another containing no nitrogen, were added to the same base fuel Ref1 in various concentrations to blend a number of fuels with different cetane ratings. The experimental fuels used in this part of the study are shown in Table 4.

Table 4 Experimental Fuels for Comparison of Cetane Improvers

Fuel Makeup	Base Fuel*	Other Type			Nitrate Type		
C. I. used	none	CI1 (contains no nitrogen)			CI2 (2-ethyl-hexyl nitrate)		
Amount %	0.0	0.3	0.6	1.0	0.16	0.42	1.0
C. N.	43.9	49.6	56.3	61.9	49.9	54.7	64.1
* Base Fuel used - Fuel Ref1							

The NOx emissions for fuels whose cetane numbers were enhanced by the two cetane improvers are shown in Fig. 1. The increase in the cetane number reduced the level of NOx emissions in both cases. The changes observed in NOx emission levels were the same with the two improvers. Contrary to common beliefs, the nitrogen introduced by 2-ethyl-hexyl nitrate did not appear to have any measurable effects on NOx emissions. The improvement in ignition quality resulted in a decrease in NOx emissions instead.

The effect of nitrate type cetane improver on different base fuels were investigated by adding the cetane improver into two different base fuels and comparing their emission results. One of the base fuels was Ref1, a conventional type diesel fuel with an aromatic content of about 25%. The other was S30A, a synthetic type fuel with an aromatic content of about 30%. The concentrations of the cetane improver added and the resulting cetane numbers are shown in Table 5.

Table 5 Experimental Fuels for the Investigation of the Effect of Base Fuels

Base Fuel	Ref1				S30A			
%v C. I.	0.0	0.16	0.42	1.0	0.0	0.12	0.3	1.0
CN	43.9	49.9	54.7	64.1	36.5	41.3	46.3	50.9

The regulated emissions are compared in Fig. 2 for the two base fuels. The change in NOx emission levels with the cetane number for the two base fuels were similar in the cetane number range where the two fuels overlap. For both base fuels, a decrease in NOx was observed when cetane number was increased. The effects of cetane number seemed to be smaller in cetane number ranges lower than 40 and higher than 55. Both fuels showed general increases in PM emissions when cetane number was increased. However, the effect of cetane number on the synthetic fuel behaviour is not as clear as that of the conventional fuel.

The two base fuels, Ref1 and S30A, had aromatic contents in the level of 25-30%. To further show the effect of cetane number, two fuels with high cetane number but low aromatic contents were examined. One was a low aromatic conventional diesel fuel (Ref3) with a total aromatic content of 5%. The other was obtained by adding 2 ethyl hexyl

Table 6 Experimental Fuels for the Investigation of High CN and Low Aromatics

	S10B	S10B + C. I.	Low Aromatic Diesel
%v C. I.	0	0.5	0
CN	43.4	55.8	55.4

nitrate into fuel S10B, a synthetic blend with a total aromatic content of 10%. The cetane numbers of the three fuels used in this part of the study are shown in Table 6.

The emission results of these three fuels are plotted in Fig. 2 together with the other fuels. The NOx emissions of S10B exhibited the same decreasing trend when cetane number was increased from 43.4 to 55.8. This indicates that the effect of cetane improver on NOx emissions is the same on low aromatic fuels as it is on high aromatic fuels. The increase in cetane number did not seem to cause a higher PM emission level for S10B.

Both fuels with low aromatic contents and high cetane number exhibited NOx emission reductions compared to commercial diesel fuels. An increase in cetane number from 45 to 55 and a reduction in total aromatic content from 30% to 10% would most likely bring down NOx emissions by 5 to 10%.

Conclusion

The results of this study can be summarized as follows:

- The nitrogen introduced by the nitrate type of cetane improver did not appear to have a measurable effect on NOx emissions. The same decreasing trends were observed when the cetane number of the fuel was increased by a nitrogen-containing cetane improver and by a cetane improver which contained no nitrogen.
- The effects of nitrate type cetane improver on the emission characteristics of the conventional type base fuels appeared to be the same as on synthetic base fuels. The effects of cetane improver were also similar for base fuels having different aromatic contents.
- An increase in cetane number from 45 to 55 combined with a reduction in total aromatic content from 30% to 10% would most likely bring down NOx emissions by 5 to 10%.

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References

[1]. Xiaobin Li, Wallace L. Chippior, and Ömer L. Gülder, "Effects of Fuel Properties on Exhaust Emissions of a Single Cylinder DI Diesel Engine", SAE Paper 962116.

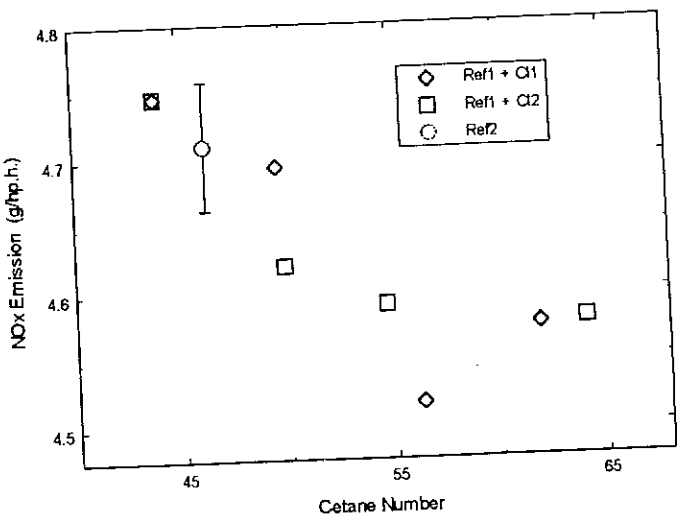

Figure 1 NOx Emissions from Fuels Enhanced by CI1 and CI2

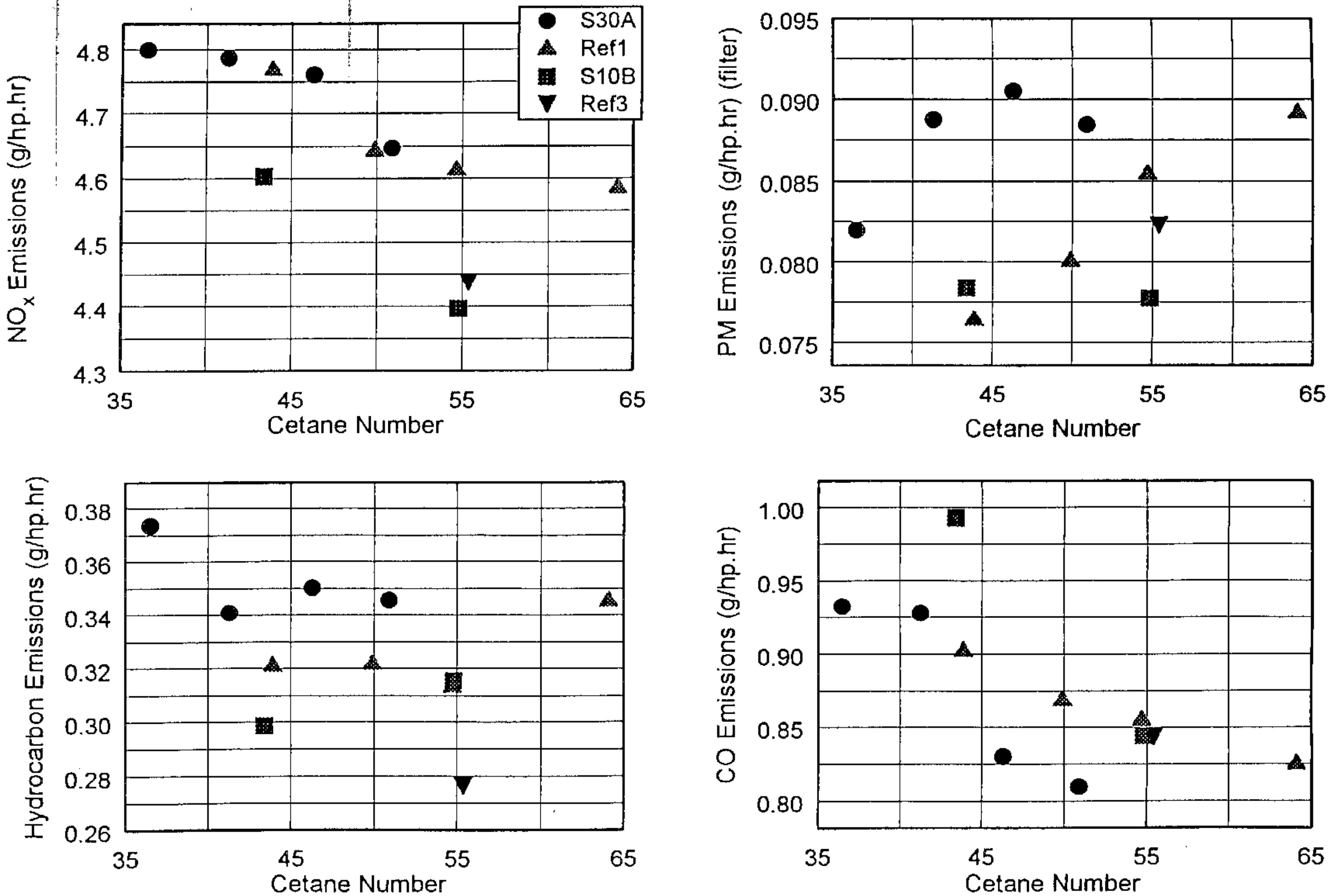

Figure 2 Effects of Cetane Improver on Emissions

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