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Experimental Analysis of the Effects of Fuel Injection Pressure and Fuel Cetane Number on Direct Injection Diesel Engine Emissions

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Abstract

The effects of different fuel cetane numbers and fuel injection pressures on a diesel engine emission were investigated. For this purpose, fuels with 46, 51, 54.5 and 61.5 cetane numbers were tested in a 4-stroke, 4-cylinder, turbocharged direct injection diesel engine. Measurements were conducted for injection pressures of 100, 150, 200 and 250 bars.

Key words: Diesel engine, Injection pressure, Emission, Cetane number.

Introduction

Combustion in a diesel engine is a complicated physical and chemical process starting after the injection of fuel into the combustion chamber and continuing until the exhaustion of the burnt gases. The reason for the complication is that combustion depends on many different parameters such as the mixing of air and fuel, injection pressure and time (Safgönül, 1989; Borat *et al.,* 1994). Fuel vaporisation is also a complex process in the combustion chamber (Chigier, 1971).

This rate of heat release depends on the amount of fuel injected, ignition delay and the combustion process (Safgönül, 1989; Bosch, 1994).

Diesel engine performance, combustion efficiency and emissions are simply related to the engine design, operating parameters and fuel properties (Challen and Barnescu, 1999, Öz, 1976). These parameters are important for optimising engine performance and for reducing emissions. Diesel fuel chemical contents and characteristics govern emissions and power-torque characteristics.

An insufficient combustion process in the engine cylinder and fuel properties also play a significant role in increasing or decreasing exhaust pollutants. Various investigators have reported that cetane number has an effect on exhaust emissions (Ullman *et al.*, 1994; Kent *et al.*, 1995).

In the present study, the variation of injection pressure and fuel cetane number and their effects were investigated.

Effects of Diesel Fuel Properties and Fuel Quality on Exhaust Emissions

Hydrocarbon contents in diesel fuel affect the combustion process. Fuel cetane number is increased by the paraffinic hydrocarbons in the fuel. The ignition delay period is reduced by increasing the cetane number and this allows the stable running of the engine (Safgönül, 1989; Borat *et al.*, 1994; Bilginpek, 1991; Petrol Ofisi, 1980). The cetane number also affects the combustion efficiency and this ensures the engine can be started easily. However, if the cetane number is excessively higher than the normal cetane number of 46 then the ignition delay will be too short to spread the fuel into the combustion chamber. As a result of this shorter ignition delay and the normal cetane number of 46, the engine performance and smoke value will increase (Taylor, 1994). In the case of a lower cetane number, knocking occurs in the engine.

The cetane number affects exhaust emissions (Broering and Holtman, 1974; McMillan and Halsall, 1988; Den Ouden *et al.*, 1994; Ullman, 1989; Lange *et al.,* 1993; Akasaka and Sakurai, 1994). The variation in NOx emissions with cetane number is shown in Figure 1 (Cunningham *et al.*, 1990). It is clearly seen from the graph that NOx decreases when the cetane number is increased (Lange, 1991; Sienicki *et al.,* 1990).

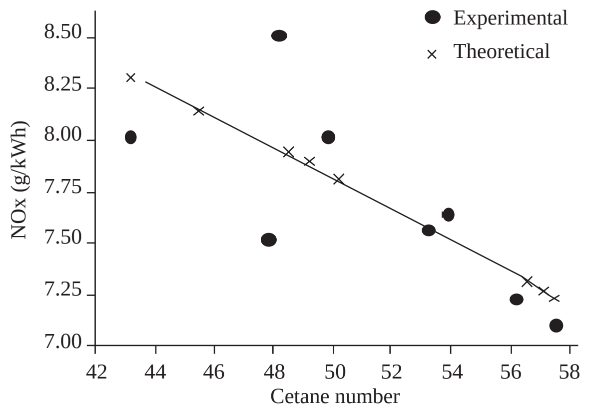


Figure 1. The effect of cetane number on NOx emissions (Cunningham et al., 1990).

The physical properties of the fuel such as viscosity, volatility and flash point also affect the combustion process. The viscosity affects the pulverisation and vaporisation of the fuel and the volatility ensures good mixing of the fuel with air. In order to increase the cetane number some additives (e.g., aniline nitrate) can be used to reduce the ignition delay (Karakuş, 2000).

Effect of Injection Pressure on Emissions

Pressurised fuel is injected into the engine cylinder. Injected fuel droplets get smaller as the injection pressure increases and NO_x formation is decreased by reducing the ignition delay (Chigier, 1971; Horrocks, 1994).

It can be seen from Figure 2 that when injection pressure increases the smoke value is reduced (Chigier, 1971). Particulate composition is largely dependent on the operating point and the combustion process (Schafer and Van Basshuysen, 1995). NO_x variation was studied by İçingür *et al.* for a 6-cylinder diesel engine (İçingür *et al.,* 1995).

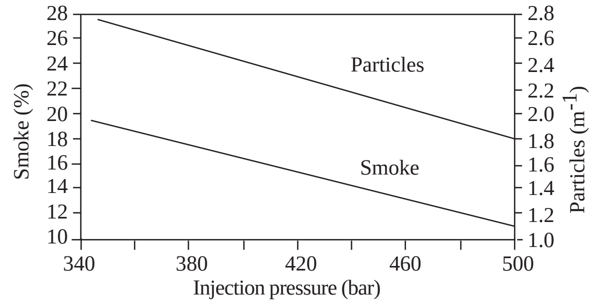


Figure 2. Variations in smoke levels with injection pressure (Karakuş, 2000).

Experiments

The properties of the test fuels used for the experiments are given in Table. The fuels were supplied by Tüpraş Co. For the calculation of the aniline point, the API gravity at 50% of the boiling point of the fuels was determined according to standard ASTM D 611 (ASTM D 611-82).

The diesel index was calculated using these experimental results and the formula given below:

$$DI = \frac{\text{API gravity}\,(60\ ^{o}F) \times \ \text{Aniline point}\ \ (^{\circ}F)}{100}$$

The cetane number (CN) can be calculated as follows (Gürü *et al.*, 2002):

$$\text{CN} = \tfrac{2}{3}\ \text{DI} + 0.068\ [50\%\ \text{boiling point}\ (^{\circ}\text{F})] - 22$$

A Cussons-P86653 type engine test bed was used to test the engine. A schematic drawing of the engine dynamometer is shown in Figure 3. The test equipment consists of 3 units: the first is an electrical dynamometer and control panel, the second a 4-stroke 4-cylinder direct injection diesel engine, and the third a VLT-2600 gas analyser (for the measurement of smoke) and a GACO-SN gas analyser (for the measurements of NO_x, $SO_x$and CO).

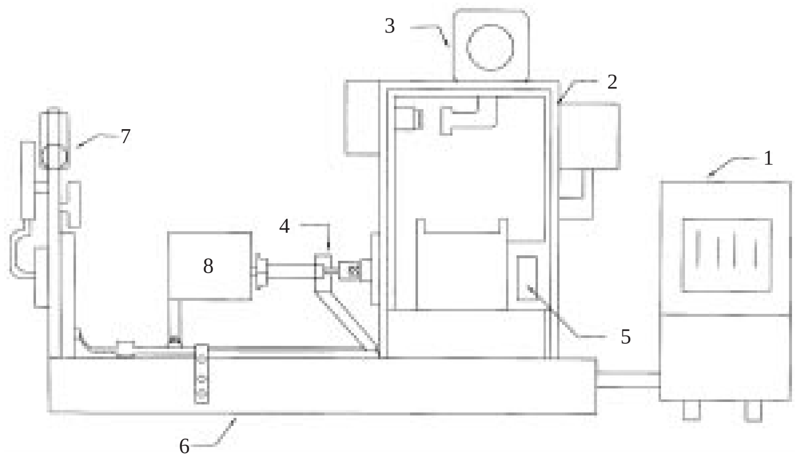
1-Control panel, 2-Device panel, 3-Air filter, 4-Shaft 5-Dynamometer,

6-Platform, 7-Cooling system, 8-Engine

The test equipment is capable of measuring engine load, speed, fuel and oil temperature, fuel consumption, power output and torque. The test data were obtained by the data acquisition system.

Table. Diesel fuel properties used in the experiments.

Fuel Type	Density At 15 °C kg/l	Sulphur (% wt)	Cetane number	Flash point (°C)	Pour point in filter (°C)
Standard Fuel	0.820-0.860	0.70 max	46	55	-10 winter/5 summer
40% 1100 Kero 45% Diesel 15% Hv Diesel	0.818	0.26	51	65	—
Diesel Oil	0.8271	0.44	54.5	69	-3.65
75% HC Diesel 25% HC Kero	0.8199	0.248	61.5	62	—



1-Control panel, 2-Device panel, 3-Air filter, 4- Shaft 5-Dynamometer, 6-Platform, 7-Cooling system, 8-Engine

Figure 3. Engine test bed.

Test Procedure

The test engine was run to reach the normal working temperature. Exhaust emission measurements were carried out first for diesel fuel with a cetane number of 46, which is a normal commercially available diesel fuel. Then fuels with cetane numbers of 46, 51, 54.5 and 61.5 were tested in that order for an injection pressure of 150 bars. All test conditions were kept constant for each diesel fuel (oil and water temperature, fuel temperature and advance values).

The diesel fuels were also tested for injection pressures of 100, 200 and 250 bars. For these parameters, exhaust emissions were measured at engine speeds from 4500 min^{-1} to 1000 min^{-1} at full engine load. All test data were collected and printed out. The results were compared with each other to show the differences and effects of cetane number and injection pressure on diesel emissions.

Test Results

The variations in NOx, SO_2, CO and smoke levels with cetane number are shown in Figures 4-7 keeping the injection pressure at a normal value of 150 bars.

It can be seen from the graphs that NO_x and SO_2 emissions decrease when the fuel cetane numbers are increased (Figures 4 and 5). The lowest value of NO_x is obtained for a 1000 min^{-1} engine speed. NO_x is decreases for speeds of 1000, 3000, 4500 min^{-1} with increasing cetane number and the type of combustion process has a significant effect on nitrogen oxide formation. An increase in cetane number ensures a shorter ignition delay and hence better combustion. The variation in SO_2 formation depends not only on increasing cetane number, but also on the sulphur contents of diesel fuels which have different cetane numbers (Figure 5).

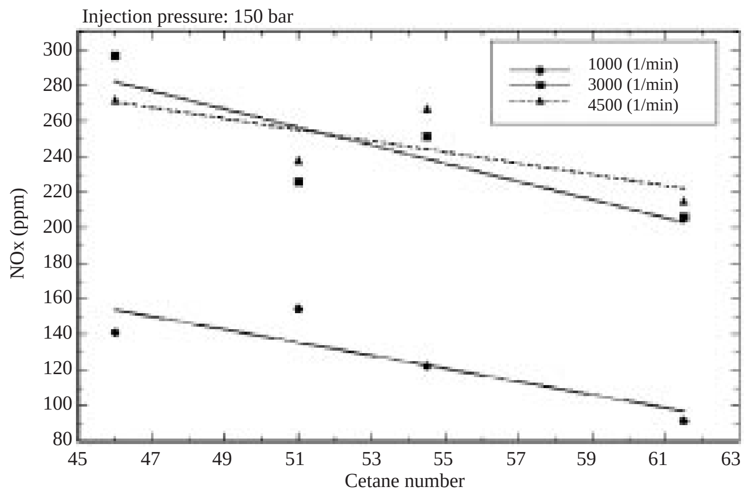


Figure 4. Variations in nitrogen oxide emissions.

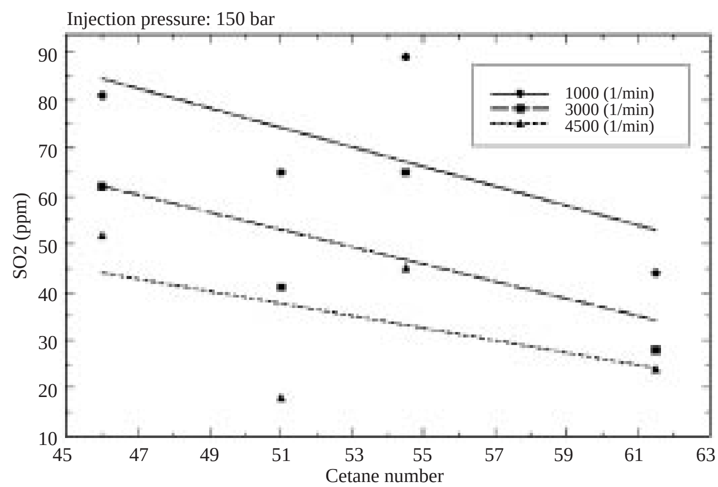


Figure 5. Variations in sulphur dioxide with cetane number.

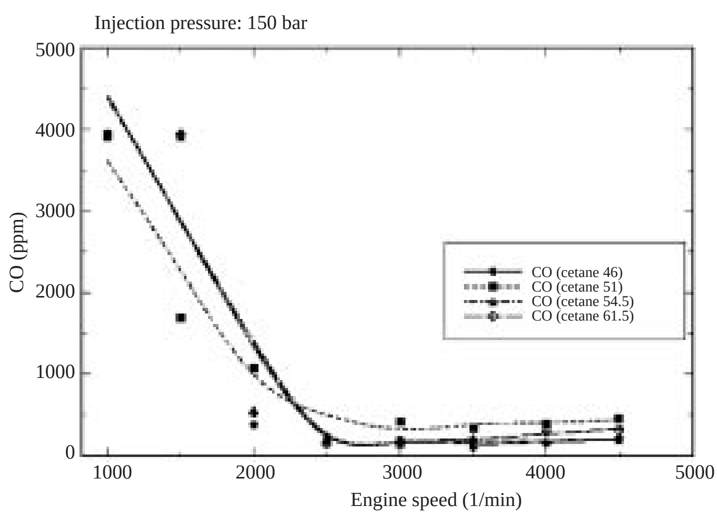


Figure 6. Variations in carbon monoxide with cetane number (full load).

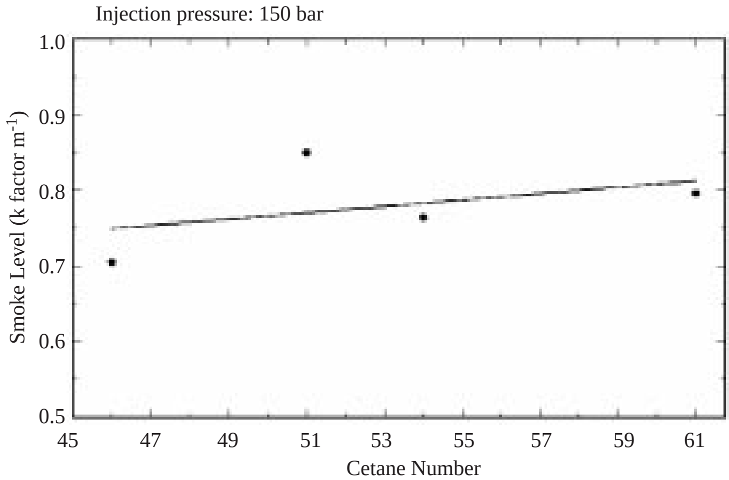


Figure 7. Variations in smoke levels with cetane number (for full load condition at 2500 min^{-1}).

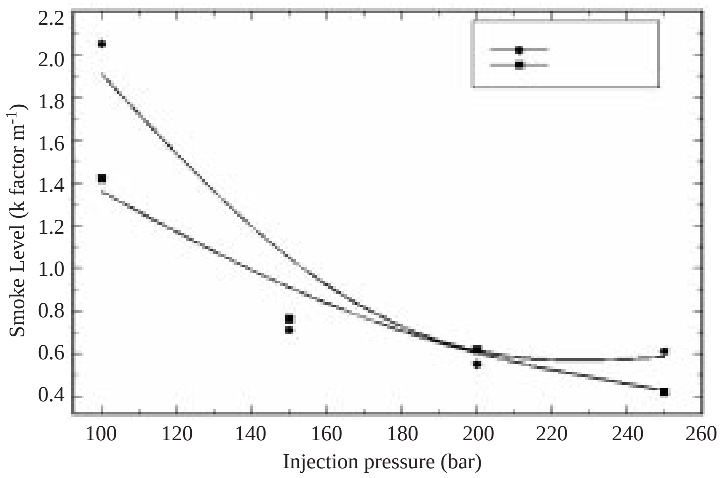


Figure 8. Variations in smoke levels with injection pressure (for full load condition at 2500 min^{-1}).

A reduction in CO emission can be seen at lower engine speeds when the cetane number is increased from 46 to 54.5. At higher speeds (above 2500 min^{-1}) the CO level is slightly increased for a fuel cetane number of 54.5 (Figure 6). This component is an intermediate product in the combustion of a hydrocarbon fuel, and so its emission results from incomplete combustion. Emissions of CO are therefore greatly dependent on the air-fuel ratio relative to the stoichiometric proportions. As diesel engines operate with an overall lean mixture, their CO emissions are normally well below legislated limits and of not much concern. Any CO from diesel engine is due to incomplete mixing, with combustion taking place in locally rich conditions (Challen and Barnescu, 1999).

The variations in smoke level with cetane number are given in Figure 7. The variations in smoke level with injection pressure are indicated in Figure 8. Although the smoke level slightly increases with fuel cetane number, in the case of changing the injection pressure, the smoke level is affected by pressure rather than the cetane number. Hence, while the injection pressure is increased from 100 to 250 bars, the smoke level is reduced.

Conclusion

In order to improve engine performance and reduce pollutant emission it is necessary to investigate both the engine's design parameters and fuel properties. In this study, the effects of fuel properties and fuel injection pressure on diesel engine emissions were investigated.

For an injection pressure of 150 bars NOx emission decreases about 10% when the fuel cetane number is increased from 46 to 61. This result indicated that an increased cetane number improves the combustion process and NOx emission decreases. Unlike NOx emission, an increasing cetane number at some engine speeds increases CO and smoke emissions.

The smoke level was very high when the injection pressure was reduced to 100 bars. This seems to depend on the injection pressure rather than fuel cetane number. It is understood that premixing in the combustion process is not sufficient because of the dripping of fuel particles due to low injection pressure.

NOx and SO_2 emissions were improved at an injection pressure of 200 bars. It can be seen from the results that smoke formation is higher at an injection pressure of 100 bars.

CO emissions may be increased at higher engine speeds (2500 and higher) when the cetane number is increased.

Other fuel properties such as fuel density and the contents of the diesel fuel should be investigated.

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