



Effect of Fuel Cetane Number on Multi-Cylinders Direct Injection Diesel Engine Performance and Exhaust Emissions

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Abstract

Due to the energy crisis and the stringent environmental regulations, diesel engines are offering good hope for automotive vehicles. However, a lot of work is needed to reduce the diesel exhaust emissions and give the way for full utilization of the diesel fuel's excellent characteristics.

A kind of cetane number improver has been proposed and tested to be used with diesel fuel as a means of reducing exhaust emissions. The addition of (2-ethylhexyl nitrate) was designed to raise fuel cetane number to three stages, 50, 52 and 55 compared to the used conventional diesel fuel whose CN was 48.5. The addition of CN improver results in the decrease brake specific fuel consumption by about 12.55%, and raise brake thermal efficiency to about 9%.

Simultaneously, the emission characteristics of four fuels are determined in a diesel engine. At high loads, a little penalty on CO and HC emissions compared to baseline diesel fuel. NO_x emissions of the higher CN fuels are decreased 6%, and CO of these fuels is reduced to about 30.7%. Engine noise reduced with increasing CN to about 10.95%. The results indicate the potential of diesel reformation for clean combustion in diesel engines.

Key words: *CN improver, performance, exhaust emissions, NO_x, UBHC, CO, CO₂, noise.*

1. Introduction

Diesel fuel comes in several different grades, depending upon its intended use. Like gasoline, diesel fuel is not a single substance, but a mixture of various petroleum-derived components, including paraffins, isoparaffins, naphthenes, olefins and aromatic hydrocarbons, each with their own physical and chemical properties. Diesel fuel must satisfy a wide range of engine types, differing operating conditions and duty cycles, as well as variations in fuel system technology, engine temperatures and fuel system pressures. It must also be suitable for a variety of climates. The properties of each grade of diesel fuel must be balanced to provide satisfactory performance over an extremely wide range of circumstances [1 & 2].

Probably the most familiar diesel fuel property to end users and for service and repair professionals is ignition quality, as expressed by cetane number. The cetane number (CN) is a measure of the ignition quality of diesel fuel

based on the ignition delay in an engine. Consumers often think the cetane number is similar to the octane number for gasoline, but that is not the case. Octane is a measure of a spark ignition engine fuel's (gasoline) ability to resist engine knock. Diesel cetane ratings work in the opposite direction. The higher the cetane rating, the shorter the ignition delay and the better the ignition quality. Reaching desired cetane levels also limits the aromatic content of diesel fuel [3 & 4].

Similar studies, (Ullman, 1989 & Ullman, 1990) [5 & 6] conducted that the value of the fuel CN was the key to reduce HC and CO emissions. Both the CN and aromatics content of the fuel affected NO_x emissions. NO_x increased as the CN is decreased and as the aromatics content is decreased. However, they showed that there is no simple answer to how the fuel properties affect emissions because different engines used in the investigation did not show similar effects. Cowley, 1993 [7], also reported that the main controlling factor for emissions in diesel engines

is the cetane number of the fuel, although, depending on the engine type, the density of the fuel can also have some effects. Similar trends have been observed by Gabele, 1986 [8], when recording exhaust emissions from a diesel passenger car. The fuels tested were a “high quality” fuel (CN 46.8 and low aromatic content) and a “low quality” fuel (CN 32.0 and a high aromatic content). Their results showed a decrease of up to 40% in HC, CO and NO, when using the “high quality” diesel fuel [9].

Shell and Mercedes-Benz companies have joined efforts to investigate the effects of diesel fuel properties (density, distillation range, cetane number and aromatics content) on exhaust emissions in an advanced European indirect injection (I) passenger car and a modern commercial vehicle direct injection (DI) engine [10]. Their results indicated that the CN and not the total aromatics content accounted for the variation in NO_x emissions. By increasing the CN, the NO_x emissions were reduced, particularly when raising CN from levels of 45 to 55. Above CN 55 the reductions became rather small [11 & 12].

Contradicting results were found by Rantanen, 1993 [13]. Emissions were measured from four turbocharged direct injection engines chosen as representative types of existing heavy duty engines. The cetane number was found not to be important in reducing NO_x emissions [14 & 15].

This work represents a part of a continuing research efforts carried out over years at the Machines & Equipments Engineering Dept. - University of Technology to provide improved knowledge of the combustion phenomena in fuels of internal combustion engines in general and the diesel engines in particular. The focus in this article is on investigating the effects of improving cetane number of diesel fuel, on the performance and emission characteristics of multi cylinder direct injection diesel engine under variable operating conditions.

2. Experimental setup

Experimental apparatus of engine under study is direct injection (DI), water cooled four cylinders, in-line, natural aspirated Fiat diesel engine (Fig. 1), whose major specifications are shown in Table 1. The engine was coupled to a hydraulic dynamometer through which load was applied by increasing the torque. This dynamometer was calibrated at the Central

Organization for Measurements and Quality Control-Baghdad.



Fig. 1. Photo of the Test Internal Combustion Engine.

Table 1, Tested Engine Specifications .

Engine type	4cyl., 4-stroke
Engine model	TD 313 Diesel engine reg
Combustion type	DI, water cooled, natural aspirated
Displacement	3.666 L
Valve per cylinder	Two
Bore	100 mm
Stroke	110 mm
Compression ratio	17
Fuel injection pump	Unit pump 26 mm diameter plunger
Fuel injection nozzle	Hole nozzle 10 nozzle holes Nozzle hole dia. (0.48mm) Spray angle= 160° Nozzle opening pressure=40Mpa

The Multigas model 4880 emissions analyzer was used to measure the concentration of nitrogen oxide (NO_x), unburned total hydrocarbon UBHC, CO₂ and CO. The analyzer detects the CO, CO₂, HC, NO_x, and O₂ content. The gases are picked up from the engine exhaust pipe by means of a probe. They are separated from water they contain through a condensate separating filter, and then they are conveyed in the measuring cell. A ray of

infrared light (which is generated by the transmitter) is sent through optical filters on to the measured elements. The gases which are contained in the measuring cell absorb the ray of light in different wave lengths; according to their concentration. The H₂, N₂ and O₂ gases due to their molecular composition (they have the same number of atoms), do not absorb the emitted rays. This prevents from measuring their concentration through the infrared system. The CO, CO₂, NO_x and HC gases, because of their molecular composition, absorb the infrared rays at specific wavelengths (absorption spectrum). This analyzer was calibrated at the Ministry of Environment-Iraq.

Overall sound pressure was measured by precision sound pressure level meter supplied with microphone type 4615, as shown in Fig. 2; the device was calibrated by standard calibrator type pisto phone 4220.



Fig. 2. Overall Sound Pressure Used in Tests.

Four kinds of diesel fuel with different cetane numbers were selected for the study. The conventional Iraqi diesel fuel (CN=48.5) was taken as baseline diesel. A common cetane improving additive, 2-ethylhexyl nitrate (also known as iso-octyl nitrate) is used to improve diesel fuel ignitability in small concentrations. It is commonly produced by several different manufacturers; the exact product used in these tests was manufactured under the name HiTec 4103. The more formal chemical formula is C₈H₁₇NO₃, with the basic structure an ethyl hexane molecule with one of the hydrogen atoms replaced with an NO₃ nitrate radical. It was used to raise cetane number in three different rates (CN=50, 52 & 55). Fuel properties and the constitutions for the four fuels were measured at

Al-Najaf Refinery laboratory. These properties are recorded in Table 2.

Table 2, Properties of Cetane Numbers for the Four Tested Fuels.

Properties	Fuel 1 (low CN)	Fuel 2 (medium CN)	Fuel 3 (high CN)	Fuel 4 (ultra high CN)
Cetane Number	48.5	50	52	55
Density (g/ml)	0.838	0.846	0.853	0.856
Lower heating value (MJ/kg)	42.36	42.87	42.44	43.18
H:C ratio	1.8	1.87	1.88	1.99
Alkalines (%)	72	80	89	96
Olifines (%)	2	1	2	2
Aromatics (%)	26	19	17	2

The following equations were used in calculating engine performance parameters [16]:

1- Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} \text{ kW} \quad \dots(1)$$

2- Brake mean effective pressure

$$bmep = bp \times \frac{2 * 60}{V_{sn} * N} \text{ kN/m}^2 \quad \dots (2)$$

3- Fuel mass flow rate

$$\dot{m}_f = \frac{v_f \times 10^{-6}}{1000} \times \frac{\rho_f}{time} \text{ kg/sec} \quad \dots (3)$$

4- Air mass flow rate

$$\dot{m}_{a,act.} = \frac{12 \sqrt{h_o * 0.85}}{3600} \times \rho_{air} \text{ kg/sec} \quad \dots (4)$$

$$\dot{m}_{a,theo.} = V_{s,n} \times \frac{N}{60 * 2} \times \rho_{air} \text{ kg/sec} \quad \dots (5)$$

5- Brake specific fuel consumption

$$bsfc = \frac{\dot{m}_f}{bp} \times 3600 \text{ kg/kW.hr} \quad \dots (6)$$

6- Total fuel heat

$$Q_t = \dot{m}_f \times LCV \quad kW$$

7- Brake thermal efficiency

$$\eta_{bt.h.} = \frac{bp}{Q_t} \times 100 \quad \% \quad \dots (7)$$

The fuel properties show that the conventional diesel fuel has low cetane number, compared to the other improved diesel fuels. In the experiment, the above four fuel blends with different cetane numbers proportions were operated on the engine, meanwhile combustion characteristics were measured and analyzed at the same brake mean effective pressure (bmep), and these parameters were compared with those of pure diesel combustion in order to clarify the effect of cetane number on engine performance and emissions.

Before testing any other diesel fuel with a different CN, the fuel lines were purged and the fuel filters were changed. The fuel supply line was later connected to the tank and the next diesel to be tested was fueled to the system. The engine was then run for a sufficient period of time in order to ensure that the last amount of the previously used fuel which could possibly still remain in the system was consumed.

Experimental errors and uncertainties

The difference between measured and true values of quantity is known as an error. By assigning a value of that error, an uncertainty is defined. The uncertainties in each individual measurement lead to uncertainties in experiment [17]. In general, the uncertainty in the results is:

$$e_R = \left[\left(\frac{\partial R}{\partial V_1} e_1 \right)^2 + \left(\frac{\partial R}{\partial V_2} e_2 \right)^2 + \dots + \left(\frac{\partial R}{\partial V_n} e_n \right)^2 \right]^{0.5} \quad \dots (8)$$

Where:

e_R : Uncertainty in the results

R : a given function of the independent variables

V_1, V_2, \dots, V_n or $R=R(V_1, V_2, \dots, V_n)$.

e_i : uncertainty interval in the nth variable.

The partial derivative $\frac{\partial R}{\partial V_1}$ is a measure of the sensitivity of the result to a single variable.

The summarized analysis of the experimental accuracy of the measuring properties for some selected measuring devices is shown in Table (3).

From these values the experiments uncertainties can be calculated:

$$e_R = [(0.045)^2 + (0.07)^2 + (0.95)^2 + (0.98)^2 + (1.24)^2 + (0.7)^2 + (0.022)^2]^{0.5} = \mp 1.974 \quad \dots(9)$$

Table 3
Experimental Accuracies.

Measurements	Accuracies in this study
Temperatures	0.045
Air flow	0.07
Fuel flow	0.95
Engine speed	0.98
Engine torque	1.24
Sound pressure level	0.7
Emitted exhaust gases concentrations	0.022

3. Results and Discussion

Cetane number requirements of an engine will vary depending on engine size, speed and load variations, starting conditions and atmospheric conditions. Since a diesel engine ignites the fuel without a spark, proper cetane levels are very important. The air/fuel mixture is ignited by the combination of compression and heating of the air due to compression. The fuel injected into the cylinder at the precise time ignition is desired to optimize performance, economy and emissions.

Fig. 3 represents the effect of CN on brake specific fuel consumption (bsfc) for the four tested fuels. Increasing fuel CN reduces bsfc, although it is still high at low loads. Increasing fuel's CN improves combustion and raises combustion chamber temperatures. Increasing combustion chamber temperatures gives low fuel delay period, and gives better ignition. Reducing the load reduces temperatures inside combustion chamber, and increases fuel delay period, resulting in bad combustion that needs more fuel to compensate the lost power.

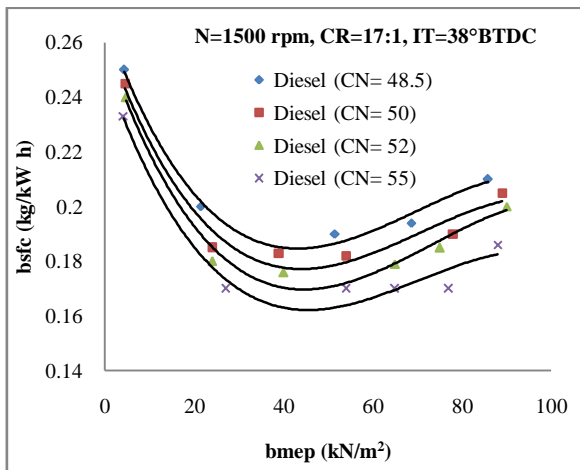


Fig. 3. CN Effect on Bsfc for Variable Loads .

Increasing CN improved brake thermal efficiency, as Fig. 4 represents. Brake thermal efficiency is a criterion of the useful used thermal power produced from fuel burning. Burning improvements causes higher brake thermal efficiency. CN indicates the ability of fuel for self ignition, its increments reduce delay period and lead to better combustion. So increasing CN in this paper from 48.5 to 55 increased brake thermal efficiency by 9% and reduced bsfc by 12.55%.

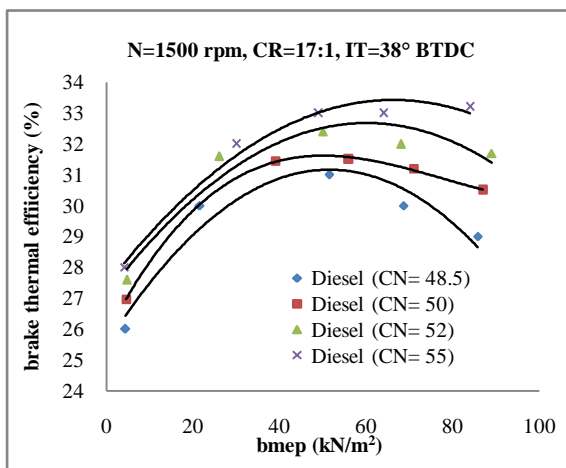


Fig. 4. CN Effect on Brake Thermal Efficiency for Variable Loads.

Exhaust gas temperatures are increased by increasing load, while increasing CN reduces these temperatures, as shown in Fig. 5. Increasing load needs more fuel to be burned which rises exhaust temperatures. On the other hand, increasing CN improves delay period, making the burning process to be completed at top dead

center, giving chance to expand exhaust gases to give maximum power to piston, and to be cooled at power stroke. Increasing CN (from baseline CN=48.5) gave reduction in exhaust temperatures by 1.2, 6.1 and 9.3% for CN 50, 52 and 55 respectively.

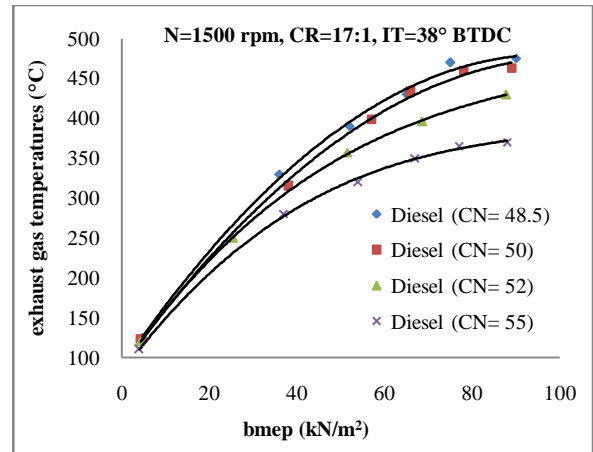


Fig. 5. CN Effect on Exhaust Gas Temperatures for Variable Loads.

Brake power (bp) increased with increasing engine speed, as Fig. 6 illustrates. Increasing CN increases bp also. Brake power increased by 1.1, 3.88 and 5.6% for CN 50, 52 and 55 respectively compared with baseline diesel fuel (CN=48.5).

CN increment reduces bsfc for all engine speed range, as Fig. 7 represents. Increasing CN increases burning efficiency giving more power with less fuel, and these improvements grow with increasing CN. Reductions in bsfc were 2.7, 3.9 and 5.5% for CN 50, 52 and 55 compared with baseline diesel (CN= 48.5).

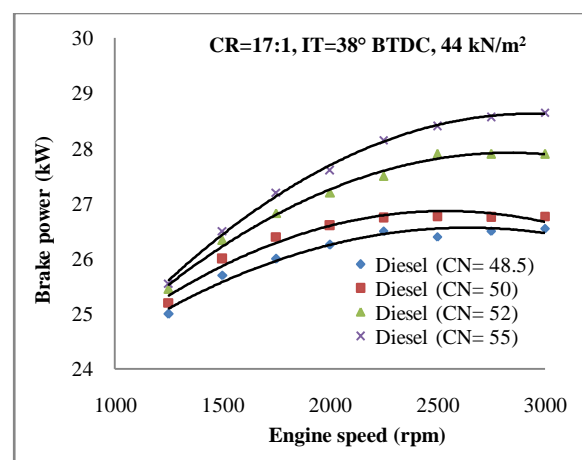


Fig. 6. CN Effect on Brake Power for Variable Engine Speeds.

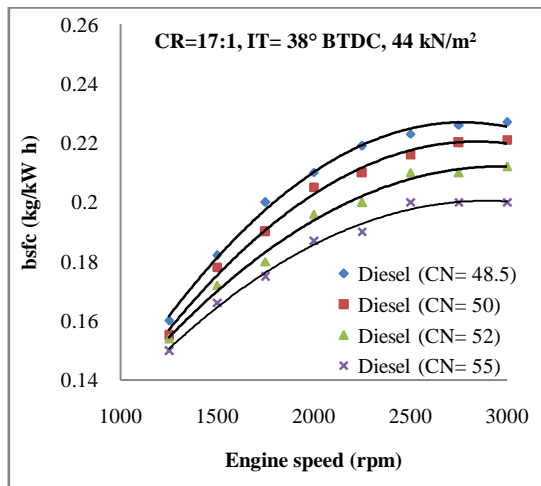


Fig. 7. CN Effect on bsfc for Variable Engine Speeds.

Raising CN reduces exhaust gas temperatures for all engine speed range, as Fig. 8 indicates. Raising fuel CN improves burning efficiency, in turn raising indicated thermal efficiency and reducing bsfc, so these improvements reflect on exhaust temperatures. The reductions were 2.4, 5.94 and 9.24% for CN 50, 52 and 55 respectively compared with baseline diesel.

Given the operating conditions, it is easy to see why cetane level is important. In addition to improving fuel combustion, increasing cetane level also tends to reduce emissions of nitrogen oxides (NOx). These emissions tend to be more pronounced when working with lower cetane number fuels as Fig. 9 shows. The decrease in CN caused an increase in NO, because of the long ignition delay.

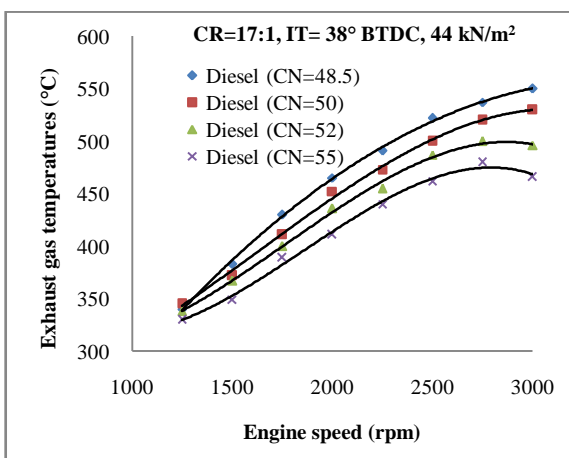


Fig. 8. CN Effect on Exhaust Gas Temperatures for Variable Engine Speeds.

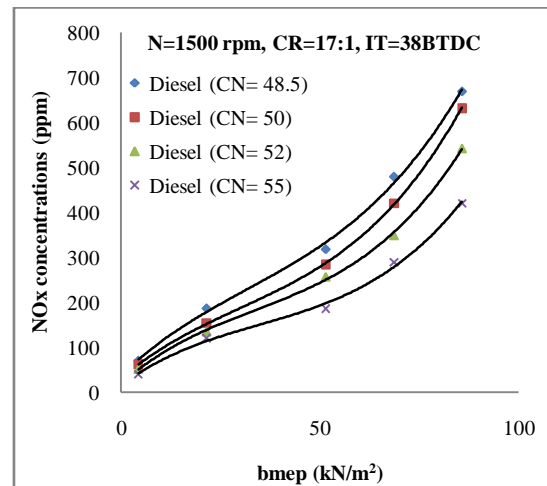


Fig. 9. CN Effect on NOx Concentrations for Variable Loads.

Fig.10 shows the variation of the CO concentration in exhaust gas with variable engine loads, when the engine was operated on commercial diesel fuel of 48.5 CN, and modified fuel of 50, 52 and 55 CN diesel fuels. Carbon monoxide is the primary intermediate product in the hydrocarbon oxidation. The presence of CO in lean fuel- air mixtures exhaust is an indication that some of the CO produced through the oxidation reactions could not be oxidized further to carbon dioxide. With very lean engine operation and small load within the partial motoring region, the CO concentrations recorded imply that they also partially originate from the incomplete combustion. These emissions are reduced with increasing CN in the fuel by 11.79, 31.2 and 56.34 for CN 50, 52 and 55 respectively compared with baseline diesel fuel (CN=48.5).

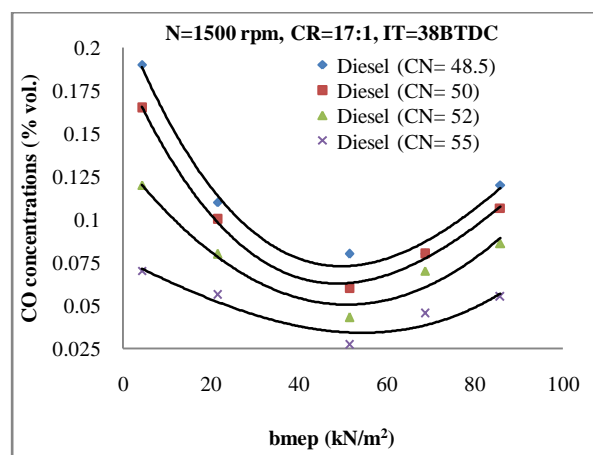


Fig. 10. CN Effect on CO Concentrations for Variable Loads.

The variations of un-burnt hydrocarbons (UBHC) concentration in the exhaust gases have a very similar trend to that observed for the CO concentrations, as Fig 11 indicates. The figure shows that at low loads a considerable fraction of the hydrocarbons representing significant quantities of fuel can pass through the engine cylinder partially burned or un-reacted. When the engine runs at very light loads, the poor atomization of the diesel fuel with increased ignition delay, large cyclic variations and low charge temperature, result in a very low gaseous fuel utilization.

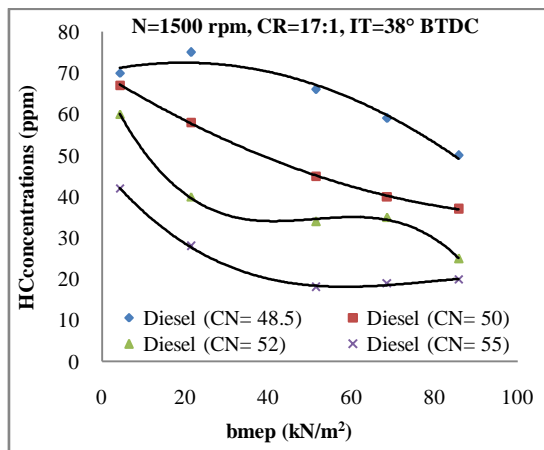


Fig. 11. CN Effect on UBHC Concentrations for Variable Loads.

At higher loads, when the diesel concentration in the cylinder charge is high enough, the UBHC tend to reduce. Diesel fuel with CN= 55 improved the utilization of the fuel up to 20% compared with baseline diesel. Also, it reduced the UBHC concentration in the exhaust, as compared to the 48.5 CN fuel. The CN 50 fuel had a slightly adverse effect. Little differences were found at very light loads, as well as at full load.

CO₂ concentrations increased with increasing CN from 48.5 to 55, as Fig. 12 represents. The CO₂ increments were due to reduction in CO and UBHC concentrations, which oxidized totally demonstrated better burning.

Engine noise reduced due to increasing CN, as shown Fig. 13. Burning improvements gave smooth movements for dynamic parts, and reduces vibration which reflects on reducing engine noise, while increasing load acts in opposite of CN effect and increases noise. From the figure it is apparent that the measured sound level is the summation of these two effects. The reductions were 3.9, 7 and 11.67% for CN 50, 52 and 55

and 55 respectively compared with baseline diesel.

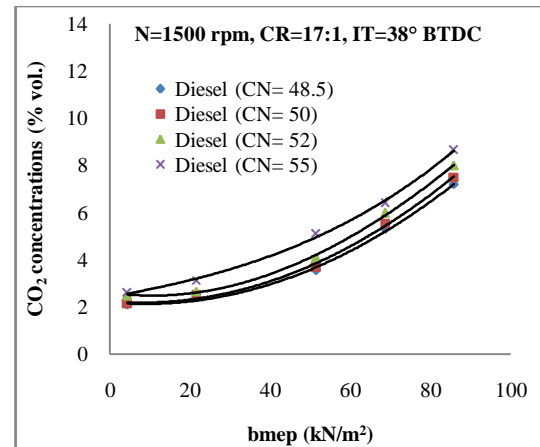


Fig. 12. CN Effect on CO₂ Concentrations for Variable Loads.

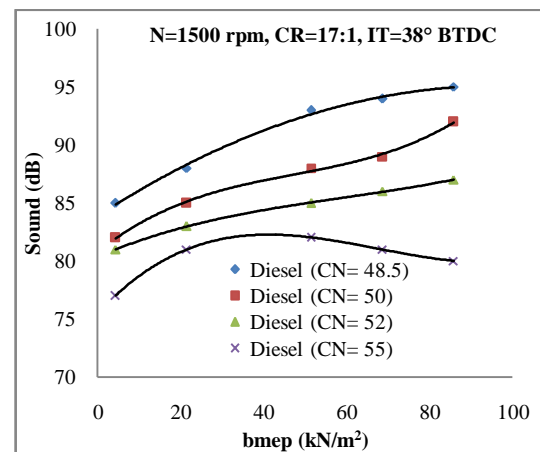


Fig. 13. CN Effect on Sound Level for Variable Loads.

The cetane number of a diesel fuel is a measure of its readiness to ignite. Fuels with higher cetane numbers will burn more efficiently, by releasing lower levels of emissions and give better fuel economy than fuels with lower cetane numbers as well as lesser emissions

As Fig. 14 reveals, NO_x concentrations are reduced with increasing CN, and it is reduced also with increasing engine speed. Increasing engine speed increases turbulence inside combustion chamber, and reduces the available time for NO_x formation. Similarly, increasing CN improves burning by reducing delay period, resulting in a complete burning which consumes all oxygen in the chamber, as a result reducing NO_x concentrations. These concentrations are reduced by 2.1, 2.9 and 6% for CN 50, 52 and 55

respectively. It can be supposed that these reductions are not enough to reduce NO_x to the wanted limits without using other techniques, like exhaust gas recirculation (EGR).

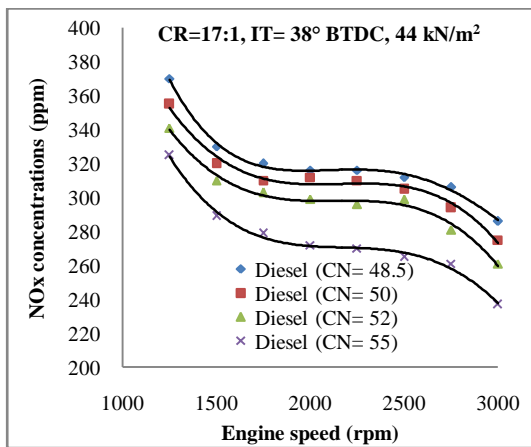


Fig. 14. CN Effect on NO_x Concentrations for Variable Engine Speeds .

UBHC concentrations are reduced with increasing engine speeds from 1000 rpm to 2250, after this speed these concentration start to increase, as Fig 15 shows. Increasing CN impact is reducing UBHC emissions due to improvements in fuel combustion and burning. While increasing engine speed from medium to high speed increases the air fuel mixture turbulence, pushing some fuel to the piston crevice where its burning will be difficult, and it will appear as UBHC.

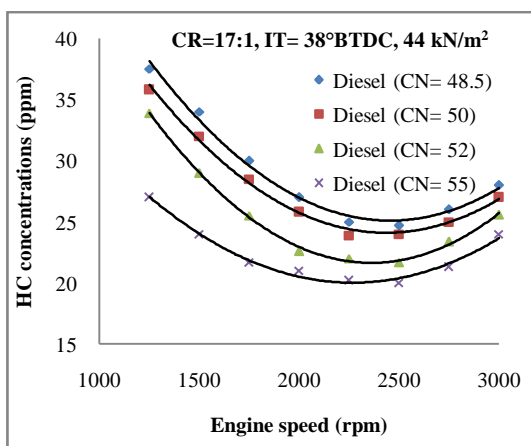


Fig. 15. CN Effect on UBHC Concentrations for Variable Engine Speeds .

CO concentrations behave as UBHC, as Fig. 16 represents. For the same reasons of UBHC

reduction and increment, CO concentrations are reduced by 5.67, 15.5 and 30.7% for CN 50, 52 and 55 compared to baseline diesel. Increasing CN has large effect in reducing CO and UBHC; it also has some effect on NO_x concentration reduction.

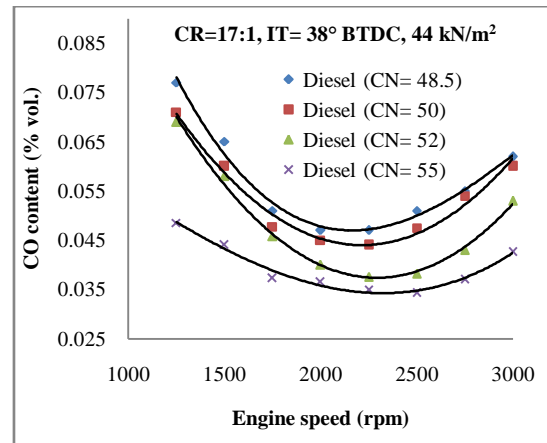


Fig. 16. CN Effect on CO Concentrations for Variable Engine Speeds.

CO₂ concentrations are increased with increasing engine speed as Fig. 17 illustrates. It also increases with increasing CN. Increasing engine speed needs more fuel to be burnt; as a result higher CO₂ concentrations will be exhausted. Increasing CN will improve burning and reduce UBHC and CO concentrations, which reflect on increasing CO₂ concentrations.

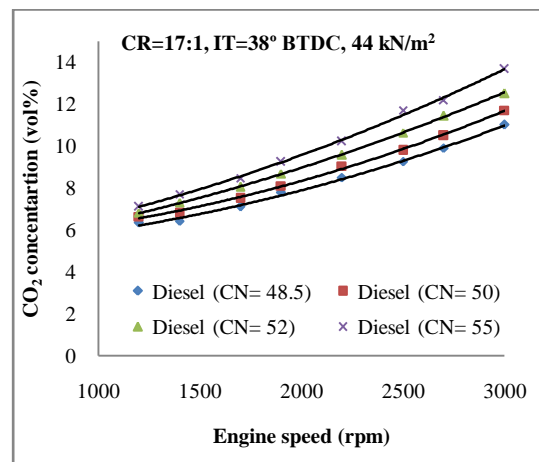


Fig. 17. CN Effect on CO₂ Concentrations for Variable Engine Speeds.

Engine noise rises at low speed and reduces at high speed, as Fig. 18 shows. It is also reduced with increasing CN. One of the main factors that are known to affect the combustion noise is the

pressure rise rate during combustion. It has also been proven that the maximum rate of pressure rise is directly proportional to the sound pressure level (SPL) in decibels observed in the main chamber of a diesel engine. However, this work proved that increasing CN reduces engine noise by 1.95, 7.8 and 10.95 for CN 50, 52 and 55 respectively compared to baseline diesel fuel.

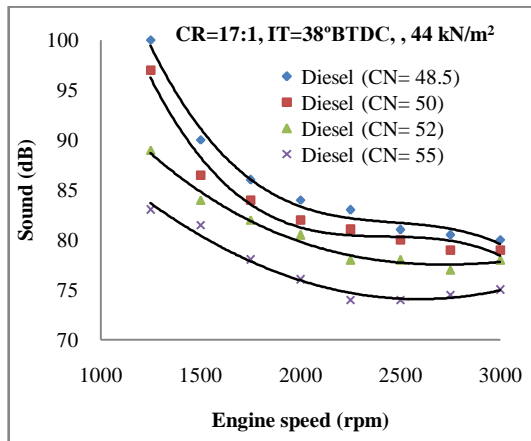


Fig. 18. CN Effect on Sound Level for Variable Engine Speeds.

4. Conclusions

The effects of CN improver on performance, gas emissions and combustion characteristics of a four cylinders, direct injection compression ignition engine fuelled with several diesel fuels containing various proportions of CN improver have been investigated, and compared to Iraqi conventional diesel fuel (baseline fuel with CN=48.5). The main conclusions obtained are as follows:

1. Fuel cetane number strongly affects the ignition delay and combustion phasing of this single-injection premixed diesel combustion mode. Increasing cetane number results in a shorter ignition delay, which for a given injection timing results in earlier combustion phasing.
2. The bsfc reduced compared to the baseline diesel. The maximum reduction reached (at constant speed and variable engine loads) was for diesel fuel with CN=55. The reduction was 12.55% compared with baseline diesel fuel. While at constant load and variable engine speed the reduction reached was 5.5% for diesel fuel with CN=55.
3. The brake thermal efficiency improved remarkably with increasing CN. The maximum increment attained was 9% for diesel fuel with CN=55 compared with baseline fuel.
4. Increasing fuels cetane numbers reduces exhaust gas temperatures. The maximum reduction obtained was 9.24% for diesel fuel with CN=55 compared with baseline diesel (CN=48.5).
5. Brake power increased with increasing fuel cetane number. The maximum increment achieved was 5.6% for diesel fuel with CN=55 compared with baseline fuel.
6. NO_x emissions decreased simultaneously when diesel engine fuelled with higher CN diesel fuels. The maximum reduction attained was 6% for diesel fuel with CN=55 compared with baseline fuel.
7. CO emission decreased with the increase of CN rating. The maximum reduction attained was 30.7% for diesel fuel with CN=55 compared with baseline fuel.
8. HC emission reduced by increasing CN rating of the fuel.
9. Engine noise reduced remarkably with increasing CN.
10. CO₂ emissions increased with increasing fuel CN.
11. The impacts of CN on emissions vary with engine operating conditions. At high load conditions, it has stronger effects on emissions. While at low loads, it has slight effects on emission reduction. With the increasing CN, NO_x emissions decrease a little, while CO emissions and unburned HC emissions decrease at most operating conditions. All the results indicate the potential of CN for clean combustion in diesel engines.
12. The study demonstrates that limited increments in CN (from CN=48.5 to CN=50) gives insignificant improvement of engine performance and exhaust emissions.

Notation

IT	injection timing
CN	cetane number
DI	direct injection
N	engine speed (rpm)
T	engine tourqe
V _{sn}	swept volume
°BTDC	degree before top dead centre
bmep	brake mean effective pressure
BTE	brake thermal efficiency

CA	crank angle
CR	compression ratio
UBHC	unburnt hydrocarbon
CO	carbon monoxide
CO ₂	carbon dioxide
NO _x	nitrogen oxides
dB	decibel
LCV	Lower calorific value

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تأثير الرقم السيتاني للوقود على أداء وملوثات العادم لمحرك ديزل متعدد الأسطوانات ذي حقن مباشر

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الخلاصة

بسبب أزمة الطاقة ومحددات التلوث البيئي المتشددة، تقدم محركات الديزل أمل جيد لمحركات المركبات، وبكل الأحوال مطلوب الكثير من العمل لتقليل ملوثات العادم لمحرك الديزل، واعطاء فرصة للاستخدام الأمثل لمواصفات احتراق وقود الديزل. تم استخدام نوع من أنواع محسنات الرقم السيتاني مع وقود ديزل لتقليل ملوثات العادم، وقد تمت إضافة (ثاني نيترات اثيل- هكسيل) للعمل على رفع الرقم السيتاني لثلاث مراحل هي 50، 52، و 55 مقارنة مع الوقود التجاري المستخدم محليا ذات الرقم السيتاني 48.5. إن إضافة محسن الرقم السيتاني نتج عنه تقليل للاستهلاك النوعي المكبي للوقود بحدود 12.5%، ورفع للكفاءة الحرارية المكبية بحدود 9%. كما تم قياس الملوثات الناتجة لأنواع الوقود الأربعة في نفس الوقت، وقد لوحظ ارتفاع تراكيز CO و UBHC عند أحمال مرتفعة مقارنة لوقود الديزل الأساسي، وقلت تراكيز NOx قليلا لأنواع الوقود ذات الرقم السيتاني الأعلى بحدود 6%، كما قلت لهذه المجموعة تراكيز CO بحدود 30.7%. وانخفض ضجيج المحرك بحدود 10.95% بزيادة الرقم السيتاني للوقود، أظهرت النتائج الحاجة إلى تحسين نوعية وقود الديزل المنتج للوصول إلى محركات ديزل ذات احتراق نظيف.