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Emissions Characteristics of Methanol-Diesel Blends in CI Engines

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دراسة عملية لملوثات خلائط ديزل-ميثانول في محركات الاشتعال بالانضغاط

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الخلاصة

أهتمت الأبحاث العلمية الحديثة بتقليل استهلاك الوقود وتقليل الملوثات السامة الناتجة من الاحتراق، بسبب الأزمة العالمية الخاصة بالطاقة ومشاكل التلوث، وذلك باستخدام أنواع من الوقود البديل، المتوفر وغير مسبب للتلوث، ويمكن اعتبار الكحول أحد مصادر الطاقة المتجددة والمتوفرة، بينما أنواع الوقود التقليدي مثل الغاز الطبيعي، النفط والفحم فانها غير متجددة.

في هذة الدراسة، تمت مقارنة مواصفات ملوثات وقود ديزل وخلائط من الديزل-الميثانول، وأجريت التجارب باستخدام محرك رباعي الاسطوانات ذي حقن مباشروعند حمل كلي وسرعة 1500 rpm، وبينت النتائج أن خلائط الديزل-الميثانول تسبب نقصان واضح بملوثات CO، الهيدروكاربونات غير المحترقة HC، وزيادة محدودة في أكاسيد النيتروجين NOx، كما أظهرت النتائج نقصان واضح للضوضاء بزيادة نسبة الميثانول بالخليط.

Abstract

Due to the energy crisis and pollution problems, investigations have focused on decreasing fuel consumption and lowering the concentration of toxic components in combustion products by using alternative, non-petroleum and non-polluting fuels. While conventional energy sources such as natural gas, oil and coal are non-renewable, alcohol can be coupled to renewable and sustainable energy sources.

In this study, the combustion characteristics and emissions of diesel fuel and methanol blends were compared. The tests were performed at steady state conditions in a four-cylinder DI diesel engine at full load at 1500-rpm engine speed. The experimental results showed that diesel methanol blends provide significant reductions in CO, unburned HC, and limited increase in NOx emissions. In addition, a reduction in engine noise was demonstrated by increasing methanol portion in blends.

Introduction

Two of the most important problems of this century are the rapid depletion of oil reserves, due to their excessive use for energy needs, and global warming. The most important cause of global warming is considered to be the reason in increasing concentration of carbon dioxide in the atmosphere. Excessive use of fossil fuels as a major energy source is the main reason for both of these problems. Among the fossil fuels, petroleum is the most convenient fuel for use in transportation; at the currently high consumption rate the known oil reserves are expected to be depleted within about 40 years, and at the current rate of consumption the known natural gas reserves are expected to be depleted within about 70 years. Although the discovery of new oil and natural gas reserves may postpone the complete depletion of these fossil fuels, significant fuel shortage problems are expected [1]. The yearly consumption rates of petroleum and natural gas increased more than 200-fold during the last century. Although petroleum and natural gas accounted for only about 2% and 1% of total energy consumption 120 years ago, today they account for about 38% and 23%, respectively [2].

The Increase of CO_2 emission rates lead to an increase in the atmospheric CO_2 concentration from about 295 ppm to 380 ppm during the last century. Additionally, the Earth's surface temperature was reported to increase by about 0.6 $^{\circ}$C during the same period [3].

Alternative fuels, especially alcohol fuels, offer a potential to mitigate national security and economic concerns over fuel supplies as well as environmental concerns over tailpipe emissions and resource sustainability. As a result, there has been continuing interest in alternative fuels, heightened recently over proposed legislation that would mandate increases in the use of renewable transportation fuels. Over the last thirty years of automotive research, a variety of alcohol fuels (primarily methanol, ethanol and blends with hydrocarbon fuels) have demonstrated to improve emissions of oxides of nitrogen (NOx) and particulate matter (PM) as well as moderately improving brake thermal efficiency [1-4].

Methanol (CH_3OH) is a colorless, odorless, slightly flammable liquid, which is also called methyl alcohol or wood alcohol. Liquid methanol can be produced from just about anything containing carbon. Potential sources include natural gas, coal, and biomass [5]. Currently most methanol is produced from natural gas, or methane, using steam, pressure, and a catalyst. Methane, a greenhouse gas, is also given off by decomposing vegetable matter in landfills (another source that could be tapped for methanol production) [6].

Pure methanol flames are nearly invisible in daylight; gasoline is added as a safety precaution to provide color to a flame. The added gasoline also serves as a smell additive. Because of its high flash point, methanol is less volatile than gasoline. It burns more slowly and at lower temperature. Methanol is transported by barge, truck, or rail [7].

Reduction of engine emissions is a major research aspect in engine development with the increasing concern on environmental protection and the stringent exhaust gas regulation. It is difficult to simultaneously reduce NOx and smoke in normal diesel engines due to the trade-off curve between NOx and smoke. One prospective method to solve this problem is to use oxygenated alternative fuels or adding the oxygenated fuels in diesel to provide more oxygen during combustion [8].

Oxygenates significantly reduce hydrocarbon, carbon monoxide, and particulate emissions, but give a slight increase in NOx emissions. There is little or no increase in fuel consumption when an oxygenated diesel fuel is utilized. Results clearly demonstrate that a reduced particulate matter emission is a key benefit achieved through oxygenated diesel fuel use [9].

Miyamoto et al. [10] investigated eight kinds of oxygenates blended with conventional diesel fuel up to 10 vol. %. The results indicated that smoke and particulate were effectively reduced without sacrificing thermal efficiency and that the reduction depended almost entirely on the oxygen content of the fuels.

Methanol is regarded as one of the promising alternative fuels or oxygen additives for diesel engines with its advantages of low price and high oxygen content [11]. However, due to the difficulty in forming a stabilized diesel/methanol blend, few reports found on this topic, and previous works were mainly concentrated on the application of diesel/ethanol blends in a compression ignition engine [12 &13].

Much work is needed in the application of diesel/methanol blends in compression-ignition engine for clarifying the basic combustion and emission characteristics and providing an approach for attaining a stabilized diesel/methanol blend with some solvent. This is the main aim of this study. It could be expected that this study will supply more information on engine emissions characteristics when operating on oxygenated fuels and provide more practical measures for the improvement of combustion and reduction of emissions.

Experimental Setup

Experimental apparatus

The experimental apparatus of engine under study is direct injection (DI), water cooled four cylinders, in-line, naturally aspirated Fiat diesel engine whose major specifications are shown in Table 1. The engine was coupled to a hydraulic dynamometer through which load is applied by increasing the torque. Fig. 1 represents a photograph for the engine rig and its accessories.

The Multigas mode 4880 emissions analyzer was used to measure the concentration of nitrogen oxide (NOx), unburned total hydrocarbon (HC), CO_2 and CO. The analyzer detects the CO, CO_2, HC and O_2 contents. The gases are picked up from the engine exhaust pipe by means of the probe. They are separated from water they contain through the condensate separating filter, and then conveyed in the measuring cell. A ray of infrared light, which is generated by the transmitter, is send through the optical filters on to the measured elements. The gases which are contained in the measuring cell absorb the ray of light of different wave lengths; according to their concentration. The H_2, N_2 and O_2 gases due to their molecular composition (they have the same number of atoms), do not absorb the emitted rays. This prevents from measuring the concentration through the infrared system. The CO, CO_2 and HC gases, because of their molecular composition, absorb the infrared rays at specific wavelengths (absorption spectrum). However the analyzer is equipped with a chemical type sensor through which the oxygen percentage is measured.

Overall sound pressure was measured by precision sound level meter supplied with microphone type 4615 Italy made, as appears in Fig. 2. The devise was calibrated by slandered calibrator type pisto phone 4220. It measures overall sound pressure in desiple units (dP). The meter was used in all expermintal tests. It was illustrated with engine level far from the engine about one meter. Four readings were taken (one from engine front, second from engine rear, the third one from the middle of the engine facing suction manifold, the last one from the other side facing exhaust manifold). The average of these readings is taken as engine noise.

Material

Three kinds of diesel/methanol blends with different methanol additives were selected for the study. Due to the low solubility of the methanol in diesel fuel, a solvent consisting of oleic and iso-butanol was added into the diesel/methanol blends to develop the stabilized diesel/ methanol blends. Fuel properties and the constitutions of three blends are given in Tables 2, 3 and Fig. 3, and the oxygen fraction in the fuel blends ranged from 5.87 to 11.1% as shown in Table 3 and Fig. 4. All chemical tests were conducted at Chemical Engineering Department- University of Technology. It can be seen that the oxygen in the fuel blends come mainly from methanol addition although the mass fraction of methanol and solvent has the same level. The solvent and stabilizer have oxygen in there chemical composition but it value is low compared to methanol. So it is reasonable to regard the influence of oxygen in the fuel blends to be the influence of oxygen from the added methanol.

The fuel properties illustrated in table 2, show that methanol has high oxygen content, while the heat value is low, and cetane number is low compared to diesel fuel.

Tests Procedure

In the experiment, the above three fuel blends with different methanol proportions were operated on the engine; meanwhile the emissions characteristics were measured and analyzed at the same load and engine speed. Furthermore, these parameters were compared with those of pure diesel combustion in order to clarify the effect of an oxygenated additive on combustion.

All tests were conducted at IC laboratory- Machines and Equipment Engineering Department- University of Technology.

Results and Discussion

Exhaust gas temperatures are increased with load increase, and increased by increasing methanol percentage in the fuel mixture by 5.9% and 11.6% for M5 and M10 respectively, and reduced by 8.7% for M15 as Fig. 5 represents. Increasing load needs more fuel to be burned, and burning more fuel means more released heat and higher exhaust gas temperatures as a result. Increasing methanol portion in the blends M5 and M10 improved combustion characteristics, and increased the released heat by using excess oxygen in the combustion chamber. The reduction accompanied with M15 was due to the reduction in the heating value of methanol. Heating value effect at M15 raised and the resultant was lower exhaust gas temperatures.

Exhaust gas temperature increased with increasing engine speed. Also it was increased by using M5 and M10 and reduced for M15, as Fig. 6 shows. Increasing engine speed needs more power which will be drawn from burning fuel, this cause more fuel to be burned and more resulted exhaust gas temperatures. The resulted exhaust gas temperatures are reduced with increasing the methanol percentage to 15% depending on reduction of fuel total heating value. While the exhaust gas temperatures increments with M5 and M10 were due to improvements in released energy because of increasing fuel oxygen content, which overcame the reduction in heating value.

The CO_2 emission which is a greenhouse causative represents fully used of engine fuel. As burning any hydrocarbon fuel must result in CO_2 and H_2O as stoichiometric products. Its concentrations are affected by many parameters the most important ones are the equivalence ratio and the fuel type. As Fig. 7 shows, CO_2 emissions increased with M5 and M10 and decreased with M15. The increments were 7.8% and 22.25% for M5 and M10 respectively, while for M15 the emissions are reduced by 11.2%.

The CO_2 emissions increase means better fuel burning due to more oxygen inside combustion chamber, whereas the reduction in M15 was due to increasing methanol quantity in the mixture. This increment reduced mixture's cetane number and changed other properties, causing combustion deterioration.

Fig. 8 gives the relation between engine speed and CO_2 concentration for different methanol blends, the same trend was observed in the exhausted CO_2 as shown in fig. 7. These emissions increased with increasing engine speed, it also increased with M5 and M10 blends and reduced for M15, for the same reasons mentioned before. Increasing engine speed caused a reduction in the available time for reaction. This is appeared in the decrement of CO_2 increasing rates for all blends.

The CO emissions in the exhaust gases represent the lost chemical energy that is not fully used in the engine. Generally, CO emission is affected by air–fuel ratio, fuel type, combustion chamber design and atomization rate, start of injection timing, injection pressure, engine load, and speed. The most important among these parameters is the air–fuel ratio. The variation in the CO emissions of the engine is shown in Figs. 9 and 10 when methanol–diesel fuel blends are compared to pure diesel fuel.

One reason for the reduction in CO emissions of the fuel blends may be lower C/H ratio of methanol, as seen in Table 3. Moreover, methanol is an oxygenated fuel and it leads to more complete combustion. Hence, these effects decrease CO emissions in the exhaust. As demonstrated in Fig. 7, the reductions in CO emissions compared to the results of diesel fuel are 6.7%, 12.56% and 19.79% for M5, M10 and M15, respectively, at increased load.

Fig. 8 demonstrates the change in the CO emissions for different methanol blends at different engine speed. As seen in the figure, it was concluded that the increased speed from 1000 to 3000 rpm increased the CO emission by about 30% for all blends.

Increasing engine speed from medium range (1500 & 1750 rpm) to high range (2500 & 3000 rpm) produced higher cylinder temperatures and deteriorated oxidation process between carbon and oxygen molecules. This lead to raise the percent change in CO emissions.

Unburned hydrocarbon emissions (UBHC) consist of fuel that is a combination of completely unburned and partially burned. UBHC emission is mostly due to the retention of unburned fuel in crevices in the cylinder. Figs. 11 and 12 show the changes in the UBHC emission of the engine using methanol–diesel fuel blends. As seen in the figures, the UBHC emission was gradually reduced when the methanol ratio increased in the fuel blend, due to the effect of different methanol contents on UBHC emission. It was found that the increasing of methanol ratio in the fuel blend decrease UBHC emission. For instance, as presented in Fig. 11 at the increased load, the UBHC emissions decreased by 4.5%, 23.6% and 52.48% for M5, M10 and M15, respectively. When methanol is added to the diesel fuel, it provides more oxygen for the combustion process and leads to the improving combustion. Alla et al. [14] stated that methanol molecules are polar and cannot be absorbed easily by the non-polar lubricating oil; and therefore methanol can lower the possibility of the production of UBHC emissions.

Fig. 12 illustrates the change in the UBHC emission results for different methanol-blended-diesel fuels at different engine speeds. As shown in the figure, the increased speed from low to medium range reduces the UBHC emissions. For M5, the reduction in the emission of UBHC was 35%, when the engine speed was increased from 1000 to 2250 rpm. As mentioned in the previous section, the increasing speed causes better fuel–air mixture in the combustion chamber; therefore, the UBHC emissions obtained are less than that of the low engine speed.

The oxides of nitrogen in the exhaust emissions include nitric oxide (NO) and nitrogen dioxides (NO_2). During the combustion in an engine, oxygen atoms dissociate at high temperatures and start the chain reaction which is the oxidation of nitrogen to NO and NO_2. Therefore, the local temperature, concentrations of oxygen and nitrogen atoms, and the time available for the oxygen– nitrogen reactions are the important parameters for NOx formation.

The variation in the NOx emission of the engine is shown in Figs. 13 and 14. The increasing methanol ratio in the fuel blend increased NOx emissions, as the figures show. For example, as illustrated in Fig. 9, increasing load push the NOx emissions to be boosted by 8.4%, 11.5% and 18% for M5, M10 and M15, respectively.

Although methanol contains 34% oxygen and its cetane number is lower than diesel fuel, it increased the peak temperature in the cylinder. Song et al. [13] indicated that increase in oxygen levels, increased the maximum temperature during the combustion, which increased NOx emissions. However, LHV of methanol is nearly two times lower than diesel fuel and latent heat of vaporization of methanol is about four times greater than diesel fuel, which decreases the peak temperature in the cylinder. As shown in the results, the exhaust temperature increased along with increasing methanol ratio in the fuel blend. It is clear from the figure that cetane number and oxygen content are more effective than LHV and latent heat of vaporization regarded with increasing peak temperature in the cylinder. Therefore, the concentration of NOx increased when the methanol content was increased in the fuel blend.

As presented in the Fig. 12, the increase in engine speed, increase the NOx emissions by 2.3%, 3.8% and 5.33% for M5, M10 and M15 respectively.

The engine is a complex source of noise whose power is made up of the acoustic energy fluxes emanating from different individual sources. The most important component of internal combustion engine noise is: acoustics of aerodynamic nature, noise generated by vibrating surfaces and acoustic energy released in the atmosphere by the engine vibration on its elastic suspension.

Fig. 15 shows the relation between engine noise levels and load. The reductions in engine noise were 5.04%, 9.76% and 14.24% for M5, M10 and M15 respectively. Increasing engine load gives hard combustion and higher noise. Whereas increasing methanol percentage improved the combustion characters without mentioning the reduction in resulted brake power. This helped in reducing engine noise. Increasing methanol portion in the blends may not improve engine performance or resulted emissions but it definitely reduced engine noise.

Fig. 16 insures the results in fig. 15 by introducing the relation between engine noise levels and speed. The resulted engine noise when using methanol blends were reduced compared with diesel fuel for all speeds. These reductions were 3.6%, 6.05% and 9.67% for M5, M10 and M15 respectively. Increasing speed increased the mechanical vibrating parts but the aerodynamics of engine combustion became smoother, so the measured noise level was the resultent of these two parameters. It is obvious now that adding methanol makes the combustion smoother and reduces the combustion noise.

Conclusions

Environmental protection is an important issue for the future of the world. Because of the reducing amount of petroleum reserves and its rising price, alternative fuels are intensively investigated for the full or partial replacement with diesel fuel. Therefore, in this study, the effect of load and engine speed on the exhaust emissions of a DI diesel engine has been experimentally investigated during the usage of methanol-blended diesel fuel. The following conclusions can be drawn from the present paper:

(1) Compared to diesel fuel, all fuel blends yielded a decrease in the unburnt hydrocarbons (UBHC), and CO emissions and an increase in NOx emissions.

(2) Adding methanol increased CO_2 emissions for M5 and M10, and reduced these emissions for M15.

(3) Adding methanol reduced engine noise by lessening combustion noise, making smoother burning.

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= 16^o Nozzle opening pressure=40 Mpa

Table 2, Fuel properties of diesel, methanol and blended fuel consititions

property	diesel	methanol	Solvent	
			Oleic	Iso-butanol
Chemical formula	$C_{10.8}H_{18.7}$	CH_3OH	$C_{18}H_{34}O_2$	$C_4H_{10}O$
Mole weight (g)	148.3	32	282	74
Density (g/cm^3)	0.86	0.796	0.8905	0.802
Lower heating value (MJ/kg)	44.40	19.68	38.65	33.14
Heat of evaporation (kJ/kg)	260	1110	200	580
Self-ignition temperature (^{o}C)	200-220	470	335	385
Cetane number	45	5	40	10
C wt%	86	37.5	76.6	64.8
H wt%	14	12.5	12	13.5

O wt%	0	50	11.4	21.7
Blended fuel 1 wt%	79.86	8.96	10.1	1.08
Blended fuel 2 wt%	71.28	13.33	14.47	0.92
Blended fuel 3 wt%	63.94	17.66	16.6	1.8

Table 3, fuel properties of diesel/methanol blended fuel consititutions

Property	Blended fuel 1	Blended fuel 2	Blended fuel 3
Lower heating value (MJ/kg)	41.73	39.89	38.64
Heat of evaporation (kJ/kg)	333.53	367.57	405.94
Cetane number	40.41	38.4	36.21
C wt%	80.47	77.98	75.5
H wt%	13.66	13.5	13.4
O wt%	5.87	8.52	11.1
O wt% contributed from methanol	4.48	6.67	8.83
O wt% contributed from solvent	1.39	1.85	2.27

Fig (1) A photo of the used engine

Fig (2) Overall sound pressure used in the tests

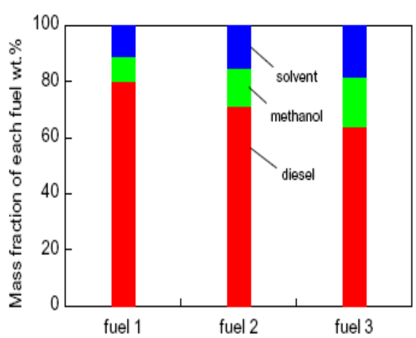

Fig (3) Consititution of the fuel blends.

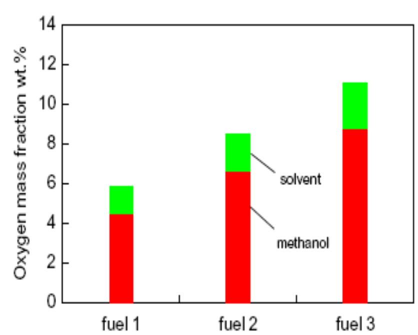

Fig (4) Oxygen mass fraction in the fuel blends

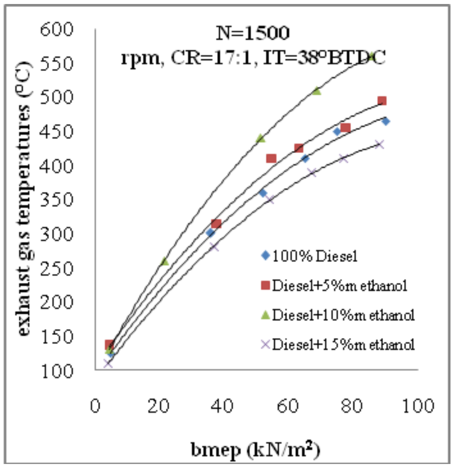

Fig (5) Methanol addition effect on exhaust gas temperatures for different bmep

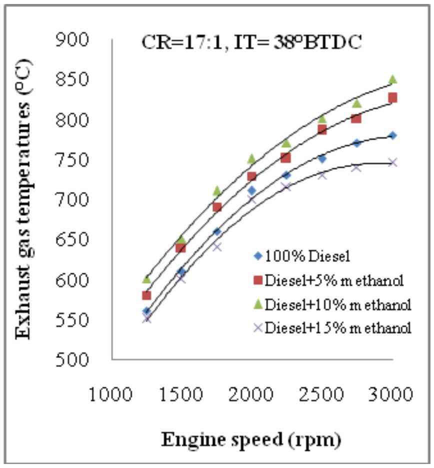

Fig (6) Methanol addition effect on exhaust gas temperatures for different engine speeds

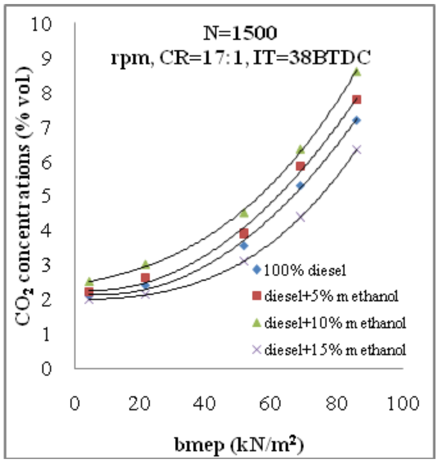

Fig (7) Methanol addition effect on CO_2 emissions concentrations for variable loads

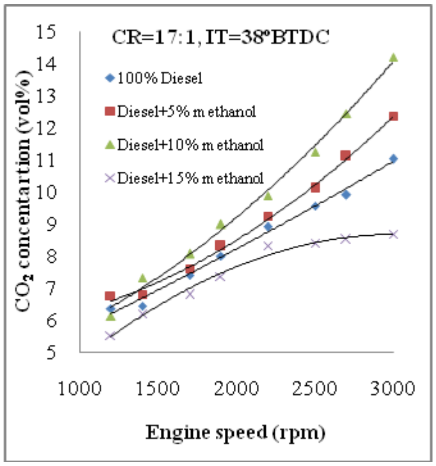

Fig (8) Methanol addition effect on CO_2 emissions concentrations for variable engine speeds

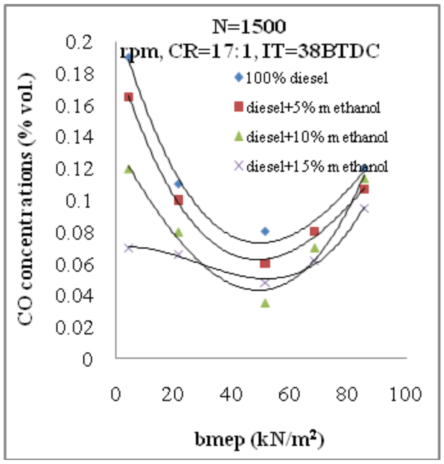

Fig (9) Methanol addition effect on CO emissions concentrations for variable loads

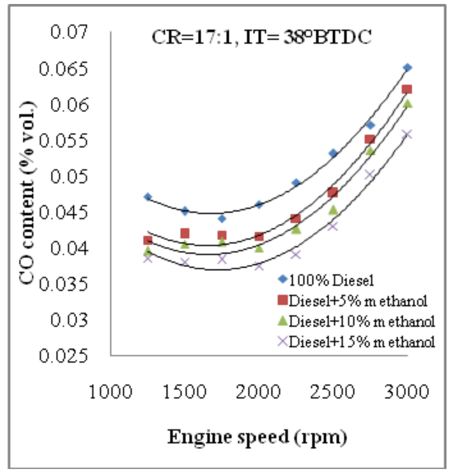

Fig (10) Methanol addition effect on CO emissions concentrations for variable engine speeds

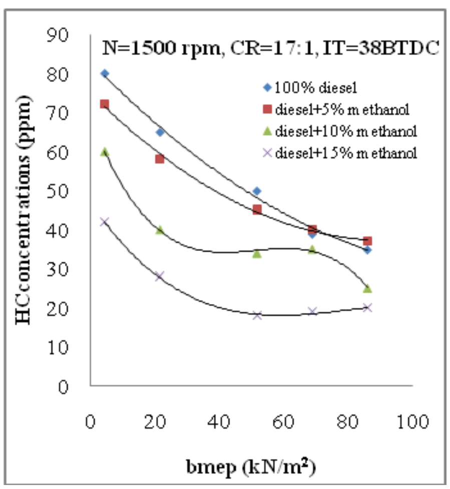

Fig (11) Methanol addition effect on UBHC emissions concentrations for variable loads

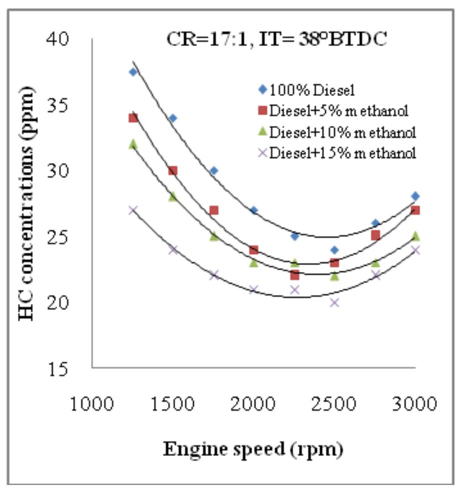

Fig (12) Methanol addition effect on UBHC emissions concentrations for variable engine speeds

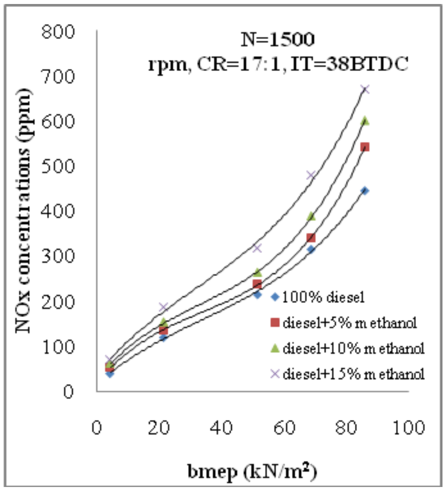

Fig (13) Methanol addition effect on NOx emissions concentrations for veriable loads

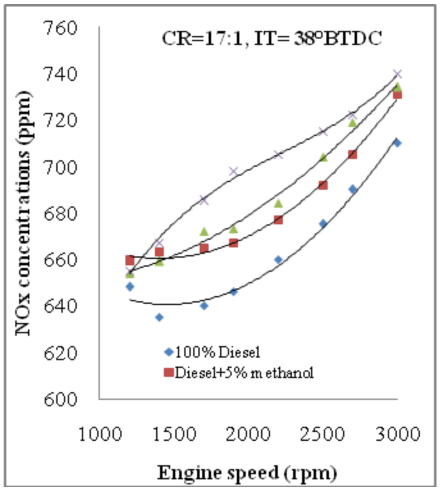

Fig (14) Methanol addition effect on NOx emissions concentrations for variable engine speeds

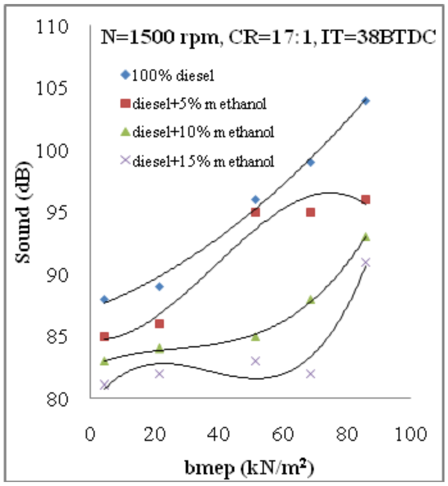

Fig (15) Methanol addition effect on noise level for variable loads

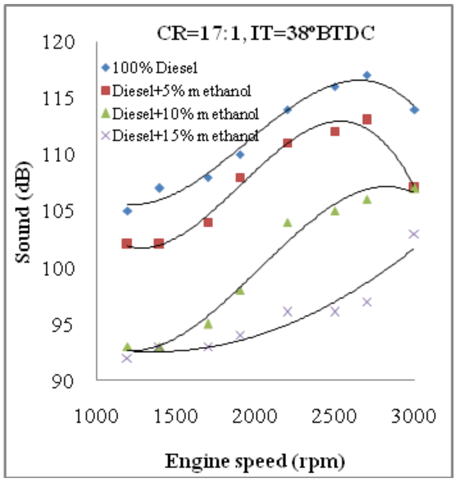

Fig (16) Methanol addition effect on noise level for variable engine speeds

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