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Evaluation of Performance and Emissions Characteristics for Compression Ignition Engine Operated with Disposal Yellow Grease

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Abstract

Biodiesel is a non-toxic, renewable alternative fuel that can be used with little or no engine modifications. Biodiesel production is currently expensive but would be more cost effective if it could be produced from low-cost oils (restaurant waste, frying oils, and animal fats). These low-cost feedstocks are more challenging to process because they contain high levels of free fatty acids.

The objective of this study was to investigate the effect of the biodiesel produced from restaurant waste feedstocks on engine performance and emissions. Two different biodiesel blends were prepared from restaurants waste yellow grease of different vegetable oils. The neat fuels and their 20% blends with diesel fuel were studied at steady-state engine operating conditions in a four-cylinder direct injection Fiat diesel engine. Although both biodiesel fuels provided significant reductions in carbon monoxide, unburned hydrocarbons and particulate matters, oxides of nitrogen increased by 7 and 11% for the yellow grease B20 and B100 respectively.

Keywords: Alternative fuel, biodiesel, diesel engine, engine emissions, engine performance, yellow grease.

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Notation

IT	injection timing	CO_2	carbon dioxide
CN	cetane number	NOx	nitrogen oxides
DI	direct injection	PM	particulate matter
N	engine speed (rpm)	dB	decibel
T	engine torque	LCV	Lower calorific value
V_{sn}	swept volume	CO	carbon monoxide
°BTDC	degree before top dead centre	UBHC	unburnt hydrocarbon
bmep	brake mean effective pressure *(kN/m^2)*	v_f	Volume of fuel flow rate *(m^3/s)*
BTE	Brake thermal efficiency *(%)*	h_o	Water hight in manometer (mm)
CA	crank angle	ρ_{air}	Air density (kg/m^3)
CR	compression ratio		

I. Introduction

The use of biofuels in automotive engines has been known for a long time. In Europe and USA the production and use of these fuels has been developing more seriously in the past ten years. This is due to the national policies aiming security of supply and reduction of CO_2 emissions. Biofuels are an important technology for reducing the emissions in transport, as they do not lead to any additional CO_2 emissions released to the air (Kadarohman1, 2010 and Karabektas, 2009).

Biodiesel refers to products derived from any vegetable oil or animal fat that can fuel a diesel engine (Anand1, 2009). Typical sources are canola, soybean or palm oil. Other oils will also work. Since vegetable oil crops are planted seasonally, there is a constant supply of virgin vegetable oil (Rehman, 2009). Additionally, the emissions from burning one crop of biodiesel are absorbed by the production of future crops. Therefore, biodiesel is essentially a zero emission fuel, since all emissions are reabsorbed in future crops nutrient uptake. In fact, more nitrogen is removed from the air and fixed in the soil through the growth of vegetable oil crops, than is produced from the emissions of the combustion of it in a compression ignition engine (Basha, 2010 and Coronado, 2009).

The fuel properties of biodiesel depend on the fatty acid chains of the feedstock used for transesterification. Biodiesel produced from tallow, a highly saturated fat, will tend to have a higher freezing point that can inhibit cold flow properties, although it will also have a higher cetane number (Basha, 2010 and Deshmukh, 2009). The cetane number measures the readiness of a fuel to auto-ignite when injected into the engine and is also an indication of the smoothness of combustion-a desirable characteristic in diesel fuel (Jindal, 2010).

The waste vegetable oil is commonly called “yellow grease” because of its color and viscosity. It is primarily used as an additive for animal feed. It provides a cheap source of fat for domesticated livestock. Other uses include emulsifiers for cosmetics, pharmaceuticals and vegetable oil based diesel fuel called Biodiesel. Yellow grease is not a monitored waste product. It is simply classified as a non-edible food product (Iranmanesh, 2008 and Canakc, 2001).

Yellow grease is not considered a hazardous substance, it is not considered recyclable, nor is it a solid at room temperature, so it is not regulated under solid waste disposal guidelines. Yellow grease is considered a liquid and cannot be disposed of in a land fill, but it can be combined with an absorbent material, such as kitty liter, and disposed of in a landfill in this manner. This however, increases the disposal cost of yellow grease and is not commonly practiced (Najafi, 2007).

Discharging yellow grease through the sewer system is a violation to the lows. However, it has been the source of reoccurring problems with sewer systems in many areas. Using waste vegetable oil to produce biodiesel eliminates the risks of getting rid of it by risky and un-law processes (Mittelbach, 1992). Yellow grease can be used as fuel in a compression ignition engine in several different ways. In order to be certified as such it must undergo a chemical transesterification process in which a methyl or ethyl ester is removed by adding methanol or ethanol (Knothe, 2005). The alcohol is then separated out along with a glycerol co-product, which is a market commodity. This transesterification process is commonly used to produce biodiesel all over the world and production is increasing annually (Fayyad, 2010 and Murugan, 2008).

Yellow grease can be used directly in diesel engines without modifications. However, for long term use, it must be heated prior to injection to provide proper atomization. Both transesterfied and non-esterifies (yellow grease) waste vegetable oil can be blended with diesel fuel, kerosene, or each other for use in any diesel engine (Myo, 2008).

Yellow grease was researched thoroughly in the late 70’s and early 80’s by many agricultural universities as an alternative fuel. The research concluded that yellow grease was not a suitable fuel for long term use because it creates engine deposits, nozzle coking and ring sticking (Nye, 1983).

The aim of this work is to introduce a benefit method of used frying vegetable oils from restaurants as fuel in CIE. If we assume that there are 100000 restaurants in Iraq, and these restaurants throw away 10 liters of used vegetable oils daily. That means one million liters of vegetable oils can be used as a fuel every day. If this disposal oil used as 20% blend to diesel fuel, this will reduces the need of one million liters of diesel fuel, also it will reduce the emitted emissions highly. This means taking advantage from unserviceable substance and making it useful one, without any need of importing anything from other countries.

II. Expermintal Setup

2.1. Equipments

Experimental apparatus of engine under study is DI, water cooled four cylinders, in-line, natural aspirated Fiat diesel engine 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. The Multigas mode 4880 emissions analyzer was used to measure the concentration of nitrogen oxide (NOx), unburned total hydrocarbon (HC); CO_2 and CO. **Fig. (1)** represents a schematic diagram of the experimental rig, while **Fig. (2)** illustrates a photo of the used engine with its accessories.

Diesel engines are tuned to run optimally on diesel fuel. When a different fuel is used, some changes may be necessary to achieve the same performance. Since yellow grease has a longer ignition delay (lower cetane number) than petroleum diesel, it is necessary to change the engine timing. This is simple procedure that involves retarding the injection timing; the pressure and therefore temperature are increased in the combustion chamber before the fuel is injected. This prevents early detonation of the fuel, which is damaging to the engine and inefficient.

Overall sound pressure was measured by precision sound level meter supplied with microphone type 4615, as appears in **Fig. (3)**; the device was calibrated by standered calibrator type pisto phone 4220.

Low volume air sampler type Sniffer L-30 shown in **Fig. (4)** was used to collect emitted PMs. Whatmann-glass micro-filters were used to collect PMs. These filters were weighted before and after the end of sampling operation which extend for one hour. Particulate matters (PMs) concentrations were determined by the equation (McWilliam, 2008):

$$PM\ in\ \left(\mu g/m^3\right) = \frac{w_2 - w_1}{Vt} \times 10^6$$

Where: *PM* = particulate matters concentration in (µg/m^3).
w_1 = filter weight before sampling operation in (g).
w_2 = filter weight after sampling operation in (g).
Vt = drawn air total volume (m^3)
Vt can be found by the equation:

$$Vt = Q_t \cdot t$$

Where: Q_t= elementary and final air flow rate through the device (m^3/sec).
t = sampling time in (min).

Each filter was kept in plastic bag temporarily at the end of collecting samples operation until weighting and analyzing the results.

2.2. Preparation of the used fuel

Transesterification is the transformation of one type of an ester into another type of ester known as biodiesel. To prepare the fuel for the present work 200ml of alcohol and 3.5 g of sodium hydroxide (lye) were taken in a beaker and mixed well for 5 min. To this 1 liter of used vegetable oil (disposal from several frying restaurants in Baghdad) was added and stirred for 15 min with heating at 65°C. The stirring was stopped and then the glycerin was allowed to settle down in the beaker. Later, the biodiesel (ester) was separated by washing and then boiled to remove the moisture. The problem with processing waste oils is that they usually contain large amounts of free fatty acids that cannot be converted to biodiesel using an alkaline catalyst due to the formation of soaps. The soaps can prevent separation of the biodiesel from glycerin, its co-product. An alternative way is to use acid catalysts, which some researchers have claimed are more tolerant of free fatty acids (Myo, 2008 and Mittelbach, 1992).

Conventional Iraqi diesel fuel was used as the base line fuel in present tests. The properties of the two main fuel used in the study are given in **Table (2)**. It is obvious that the biodiesel fuel has high oxygen content in its structure, so it is reasonable to regard the influence of oxygen in the fuel blends to be the influence of oxygen from the addition of biodiesel. While the heat value is low, and cetane number is low compared to diesel fuel.

In the experiment, the above tow fuel blends with different biodiesel proportions (B20, B100) were operated on the engine, meanwhile combustion characteristics and emissions were measured and analyzed at the same load and engine speed, and furthermore, these parameters were compared with those of pure diesel combustion in order to clarify the effect of an oxygenated biodiesel fuel on combustion.

2.3. Tests procedure

In the experiments, the two biodiesel blends B20 (20% yellow grease+80% diesel) & B100 (100% yellow grease) were used to operate the engine. The engine injection timing was retarded to 15 °BTDC to achieve smooth engine operation when it was fueled with B100. Injection timing was fixed at factory setting when the engine was fueled with B20 and neat diesel. Meanwhile combustion characteristics and emissions were measured and analyzed at the same load and engine speed. The resulted parameters were compared with those of pure diesel combustion in order to clarify the effect of an oxygenated biodiesel fuel on combustion. Tests were conducted at IC engines laboratory, Machines and Equipment Engineering department, University of Technology.

III. Theory

The following equations were used in calculating engine performance parameters (Keating, 2007):

Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} \quad kW$$

Brake mean effective pressure

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

Fuel mass flow rate

$$\dot{m}_f = \frac{v_f \times 10^{-6}}{1000} \times \frac{\rho_f}{time} \quad kg/_{sec}$$

Air mass flow rate

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

$$\dot{m}_{a_{theo.}} = V_{s.n} \times \frac{N}{60 * 2} \times \rho_{air} \quad \frac{kg}{sec}$$

Brake specific fuel consumpotion

$$bsfc = \frac{\dot{m}_f}{bp} \times 3600 \quad \frac{kg}{kW.hr}$$

Total fuel heat

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

Brake thermal efficiency

$$\eta_{bth.} = \frac{bp}{Q_t} \times 100 \quad \%$$

4. Results and Discussions

Brake thermal efficiency is the ratio of brake power output to power input. Brake thermal efficiency of test fuels are shown in **Fig. (5)**. Brake thermal efficiencies rise from lower to higher load level. It is because of higher power output or work done at high load level makes higher brake thermal efficiency.

From **Fig. (5)** it can be seen that brake thermal efficiency of B100 and, B20 are slightly higher than that of diesel fuel at all load levels. From this result, methyl ester fuels with more oxygen content may take better combustion and therefore they have better energy conversion rate compared to diesel fuel.

Brake specific fuel consumption (bsfc) is the rate of fuel consumption divides by the rate of power production. BSFC of test fuels are manifested in **Fig. (6)**. It is related with brake thermal efficiency. At higher load level the brake thermal efficiency is increased and brake specific fuel consumption decreased. From Fig. 6 it can be seen that the brake specific fuel consumption of B100 and B20 are higher than that of the diesel fuel. In the combustion process, to produce the same amount of heat, more amount of biodiesel fuel of lower net calorific value fuel is necessary to compensate the differences from the higher one. Therefore, the higher bsfc of methyl ester fuels are due to the lower net calorific value of these fuels. B100 with the lowest net calorific value among the test fuels shows the highest bsfc.

The presence of oxygen atoms in yellow grease structure increased its volumetric efficiency compared to diesel fuel, as **Fig. (7)** represents.

Exhaust gas temperatures increased with increasing load, as **Fig. (8)** illustrates. Using B20 and B100 reduced exhaust gas temperatures about 7.5 and 24.3% due to its lower calorific value.

Increasing engine speed from low to medium speeds increases brake power (bp) in high rates, while accelerating the engine speed from medium to high speeds reduces bp with low rates, as **Fig (9)** shows. There is a reduction in bp about 1 and 2.7% for B20 and B100 respectively.

BSFC curves of net diesel fuel at full load and variable engine speed are displayed in **Fig. (10)**. The curves show that fuel consumption at full load condition and low speeds is high. Fuel consumption first decreases and then increases with increasing speed. The reason is that, the produced power in low speeds is low and the main part of fuel is consumed to overcome the engine friction. Irrespective of fuel consumption at low speed (1250 rpm), fuel consumption is increased with increasing speed. The reason probably is that, friction power increases with increasing speed. The curves show that brake specific fuel consumption of fuel blends trends is very similar to net diesel fuel. BSFC increased with using B100 and B20 with about 23.3 and 2.5% respectively. BSFC of yellow grease blends is higher than neat diesel. A mild increase in brake specific fuel consumption is observed with biodiesel usage.

The HC emissions of the test fuel are presented in **Fig. (11)**. The cause of HC emission is mostly depending on the combustion. Incomplete combustion produces more HC emission or unburned fuel emission. If a fuel-rich mixture does not has enough oxygen to react with all the carbon, result high level of HC emission. From the experimental results, the HC emissions from all yellow grease blends are lower than that of the diesel fuel. The lower HC emission from methyl ester fuel is probably due to the oxygen in biodiesel fuel. The present of fuel oxygen allows the fuel to burn completely, so fewer unburned fuel emission result. Therefore, more oxygen in B20 and B100 show more reductions in HC emission.

The CO emissions from test fuels are exhibited in **Fig. (12)**. The cause of CO emission is similar as HC emission. Generally, CO is generated when there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. The other factors of CO emission are poor fuel air mixing; local fuel rich region and incomplete combustion will create some CO. From the experimental results, the CO emission from B20 and B100 are lower than that of the diesel fuel at all load range. Also CO emission from yellow grease fuels may be influenced by the oxygen content in the fuel. Therefore, more oxygen in B20 and B100 show more reductions in CO emission.

The CO_2 exhaust levels are exposed in **Fig. (13)**. The CO_2 emissions for B20 and B100 were only slightly higher than for the diesel fuel. Compared to diesel fuel, the CO_2 emissions of the B100 and B20 were increased by 1.8% and 0.7%, respectively. The increment was due to better fuel burning, which resulted in lower UBHC and CO concentrations.

The NOx emissions from the test fuel are declared in **Fig. (14)**. The NOx formation in diesel engine combustion is complicated. But the NOx formation in combustion process is mainly controlled by the combustion temperature and time available for formation. On the other hand, these parameters are depended on the injection timing of the fuel, ignition delay time and combustion pattern. In general, biodiesels cause the faster propagation of pressure waves and more rapid pressure rise, which may indicates the necessity of retarding injection timing several crank degrees. The earlier combustion can result higher combustion temperature and higher NOx emission as been happened. From the experimental results, there are relatively small differences in NOx emissions of yellow grease fuels and the diesel fuel at lower load level. But at 75-100% load level, about 12.28% increase occurred in B20 and 20.52% with B100. It may be caused by faster injection timing leading to earlier combustion and resulting higher combustion temperature and the NOx emission increase.

The effects of engine load on PM emissions for the testes blends are stated in **Fig. (15)**. The PM emission from yellow grease biodiesel-diesel fuel and neat diesel fuel has a few differences at 0% to 25% load level. But at 50% to 100% load level the PM concentrations from B100 biodiesel blinds is lower than that of the diesel fuel. The PM emission in case of various blends of biodiesel is less as compared to diesel as seen in the figure. The maximum reduction in PM concentration was about 29.466 % in case of neat biodiesel operation as compared to diesel at full load. This significant reduction in smoke emission indicates a better combustion due to the existence of oxygen molecule in oxygenated fuel (biodiesel blends) structure.

Compression ignition engines characterized with high engine noise, as **Fig. (16)** reveals. Using yellow grease blends reduced engine noise with about 1.1 and 3.8% respectively. Better combustion due to higher oxygen content and the lubricating effects of yellow grease were the reasons of this education in engine noise.

Biodiesel contains oxygen in its structure. When biodiesel is added to diesel fuel, the oxygen content of fuel blend is increased and thus smaller oxygen is needed for combustion. However oxygen content of fuel is main reason for better combustion and CO and HC emission reduction, as **Figs (17)** and **(18)** demonstrate. UBHC concentrations reduced from low to medium speeds then it start to increase but with lower rate. UBHC reduced for B20 and B100 about 21.5 and 56.17% respectively. CO concentration reduced with about 4.59% for B20 and 17.17% for B100 compared with neat diesel.

CO_2 concentrations increased with increasing engine speed, as **Fig. (19)** represents. B20 and B100 produce fewer concentrations compared to neat diesel with about 6.25 and 19% respectively. Diesel fuel has higher C/H ratio than biodiesel, which made diesel CO_2concentrations accede B20 and B100 concentrations.

NOx concentrations reduced slightly with increasing engine speed from low to medium speeds, as **Fig. (20)** manifests. These concentrations increased with increasing engine speed from medium to high speed. From the experimental tests NOx concentrations resulted from engine operation with B100 had the maximum concentrations, while diesel had the minimum ones. The availability of oxygen and high temperatures at high speeds are the reasons for these high NOx concentrations. While at low speeds the available time and oxygen are the reasons for the high NOx formation.

Fig. (21) evinces the engine speed effects on PM concentration when it was run at constant medium load (44 kN/m^2). The utilization of yellow grease biodiesel significantly reduced PM concentrations. According to figure PM concentrations decreased with biodiesel blends fuelling at practically all engine speeds compared with diesel. The effect of the engine operation mode on PM concentrations seemed to be fuel sensitive. The reductions in PM concentrations were 10.91 & 32.92% for B20 and B100 respectively compared with diesel fuel.

(Evans, 2000 & Akasaka, 1997) verified that smoke emissions increments or decrements are generally correlated to the sulphur concentration in the fuel. Sulfur in the fuel, results in sulfates that are absorbed on soot particles and increase the smoke emitted from diesel engines. In addition, the increase of oxygen content in the fuel contributes to a complete fuel oxidation even in locally rich zones, leading to a significant decrease of smoke. Higher reductions in PM concentrations with other types of biodiesel compared with this study were recorded by (Evangelos, 2012 & Jaichandar, 2011). The reason of this is the amount of sulfur concentration into main fuel used in this study. The Iraqi diesel fuel contain about 10000 to 15000 ppm sulfur (UNEP, 2007), while the mentioned researches used free sulfur diesel fuel.

Engine noise increases with increasing engine speed from low to medium speeds and reduces for high speeds, as **Fig. (22)** clarifies. B20 and B100 gave less noise than diesel with about 2.4 and 8.45% respectively. Biodiesel lubricating effect appears obviously by reducing engine noise.

It is very important to study the necessity to heat yellow grease to prevent pipes blockage in Iraqi weathers. Ambient temperatures in Iraq always higher than biodiesel's cloud and fog point.

5. Conclusions

From this investigation the following conclusions can be summarized:

1- Brake specific fuel consumption was found to have minimum for neat diesel as compared to biodiesel blends at all loads.
2- The brake thermal efficiency was found to increase with increase in load and there is no large difference in the brake thermal efficiency of bio diesel blends and neat diesel. Yellow grease blends have brake thermal efficiencies slightly higher than diesel.
3- The maximum NOx emissions increase with load about 12.28 and 20.52% for B20 and B100 respectively, compared to diesel fuel.
4- NOx concentrations for yellow grease blends are higher than that for diesel fuel for all the engine speed range.
5- The CO emissions emitted from the yellow grease biodiesel over all loads are lowered by up to 11.26% and 43% for B20 and B100, respectively.
6- The CO emissions emitted from the yellow grease biodiesel over all tested engine speed range are lowered by up to 4.59% and 17.17% for B20 and B100, respectively.
7- The carbon dioxide CO_2 emissions, along with the fuel consumption are slightly higher for the B20 and B100 blends.
8- The emission of unburned hydrocarbons HC for all fuels is low, for the tested engine speed range HC reduction were 21.5 and 56.17% for B20 and B100 respectively.
9- Adding yellow grease biodiesel reduced PM concentrations. The decrements in PM concentrations were about 30% for the two studied cases when B100 was used as fuel.
10- Yellow grease ability to lubricate engine parts appears by reducing engine noise for all engine speed range with about 2.4 and 8.45% for B20 and B100 respectively.

A general practical conclusion is that, tested Yellow grease biodiesel blends which were produced from used frying oils can be used safely without any modification in engine. So, blends of yellow grease could be successfully used.

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Table (1). Tested engine specifications.

Engine type	4cyl., 4-stroke
Engine model	TD 313 Diesel engine rig
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^o Nozzle opening pressure=40 Mpa

Table (2). Tested fuels specifications.

Fuel type	Calorific value (kJ/kg)	Density (g/dm^3)	Viscosity (mm^2/s at 27^{o}C)	Cetane No.	Flame point (^{o}C)	Cloud point (^{o}C)	Pour point (^{o}C)
Diesel fuel	44227	810	4.23	49	59	-13.8	-29
Yellow grease	35873	922	59	37.6	209	-2.7	-10.4

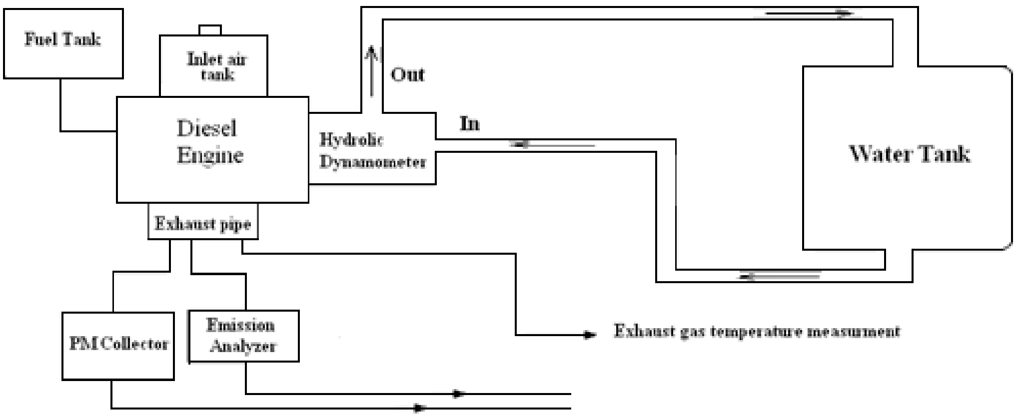

Fig. (1). A schematic diagram of the experimental rig.

Fig. (2). A photo of the engine used in present study.

Fig. (3). Overall sound pressure used in the tests.

Fig. (4). Drawing air equipment to collect PM type Sniffer.

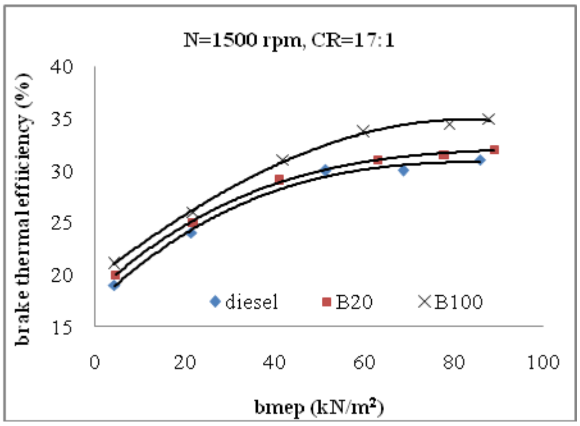

Fig. (5). Load effect on brake thermal efficiency at constant speed for the tested fuels.

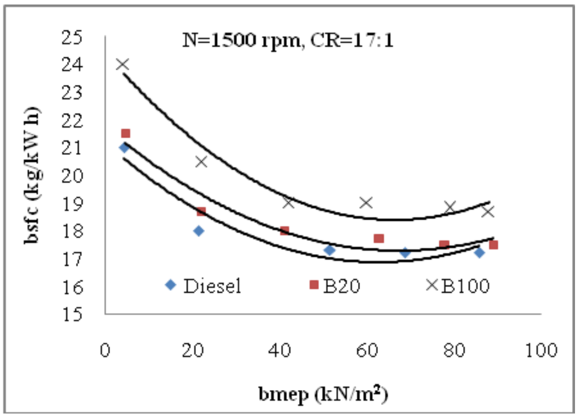

Fig. (6). Load effect on brake specific fuel consumption at constant speed for the tested fuels.

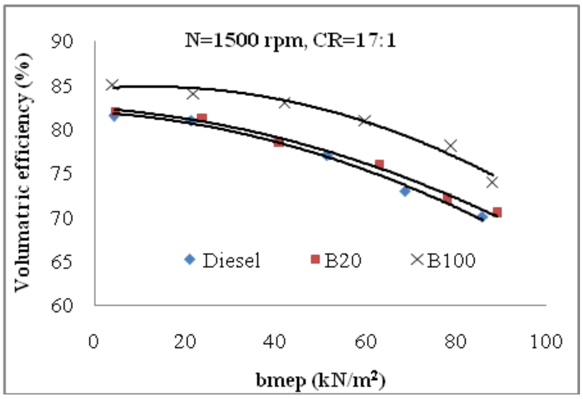

Fig. (7). Load effect on volumetric efficiency at constant speed for the tested fuels.

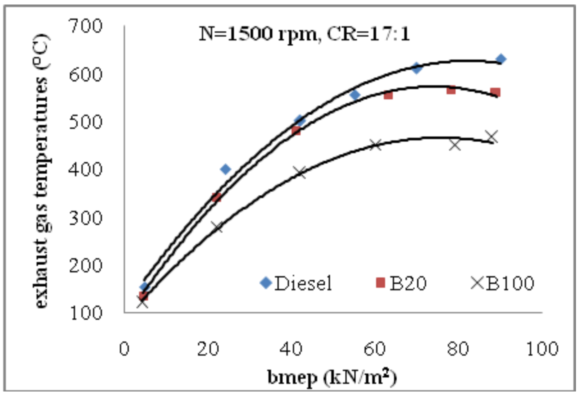

Fig. (8). Load effect on exhaust gas temperature at constant speed for the tested fuels.

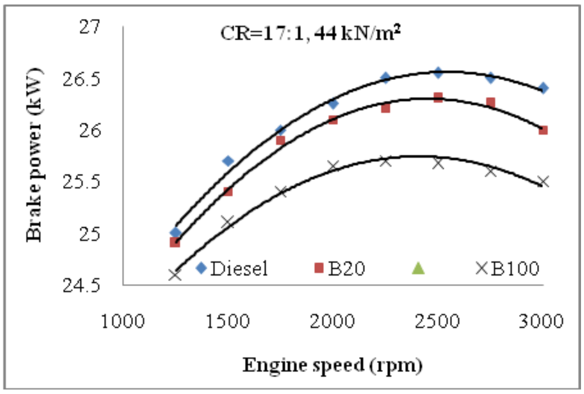

Fig. (9). Engine speed effect on brake power at constant speed for the tested fuels.

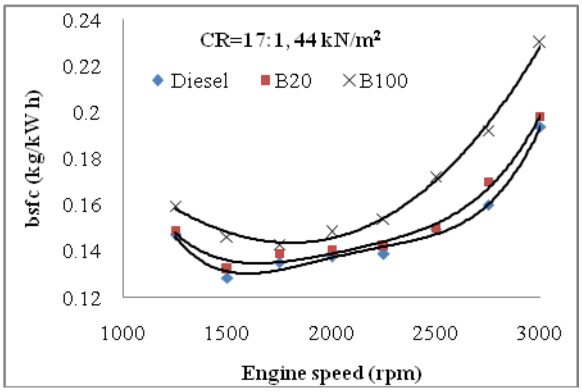

Fig. (10). Engine speed effect on brake specific fuel consumption at constant speed for the tested fuels.

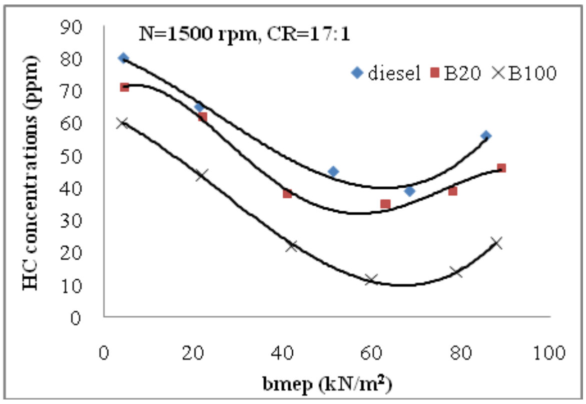

Fig. (11). Engine load effect on unburnt hydrocarbons concentrations at constant speed for the tested fuels.

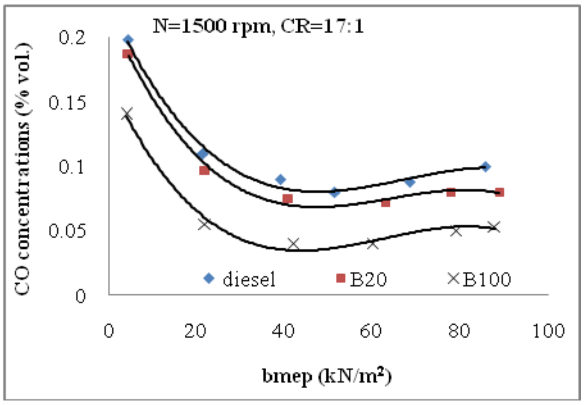

Fig. (12). Engine load effect on CO concentrations at constant speed for the tested fuels.

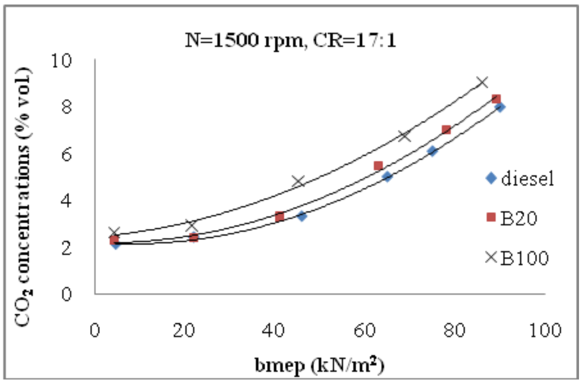

Fig. (13). Engine load effect on CO_2 concentrations at constant speed for the tested fuels.

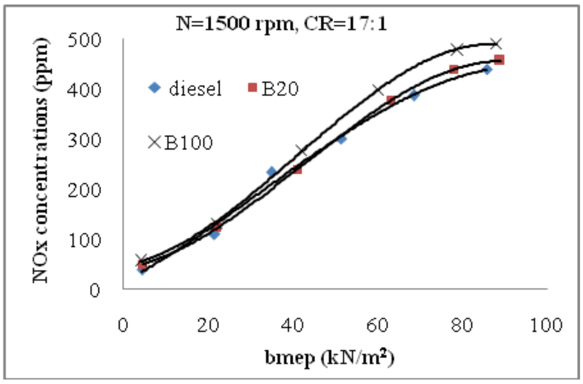

Fig. (14). Engine load effect on NOx concentrations at constant speed for the tested fuels.

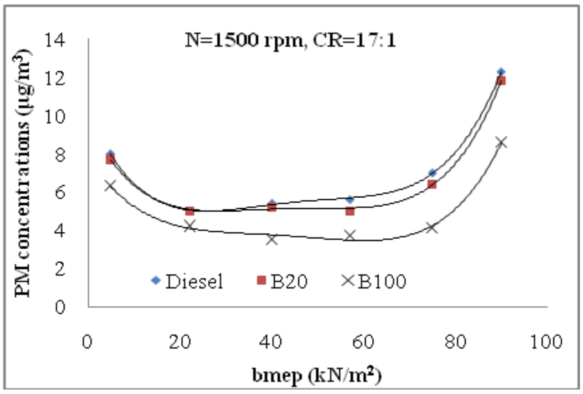

Fig. (15). Engine load effect on PM concentrations at constant speed for the tested fuels.

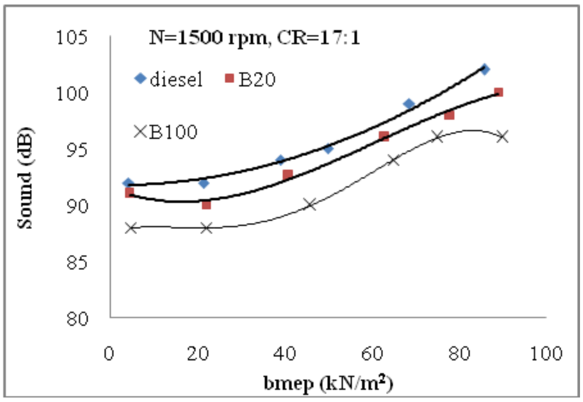

Fig. (16). Engine load effect on engine noise at constant speed for the tested fuels.

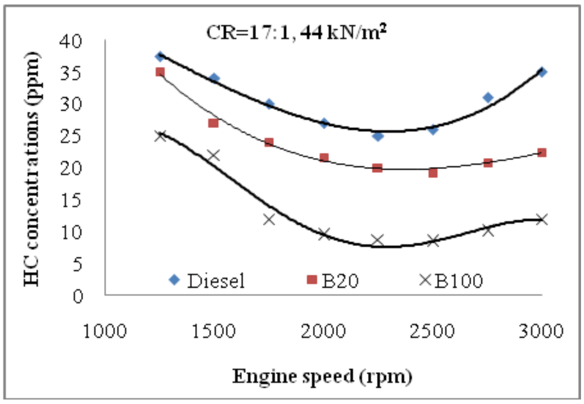

Fig. (17). Engine speed effect on unburnt hydrocarbons concentrations at constant load for the tested fuels.

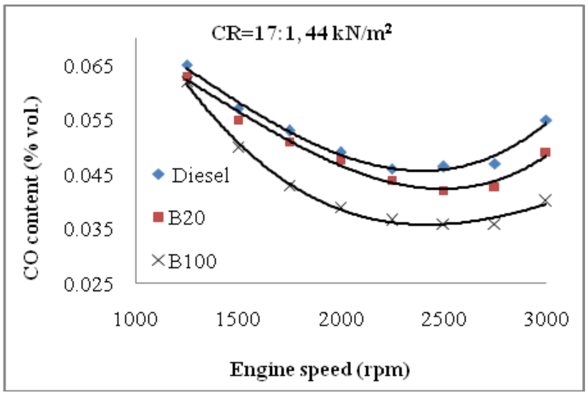

Fig. (18). Engine speed effect on CO concentrations at constant load for the tested fuels.

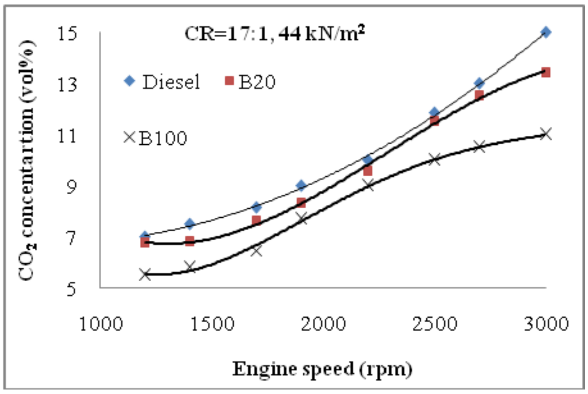

Fig. (19). Engine speed effect on CO_2 concentrations at constant load for the tested fuels.

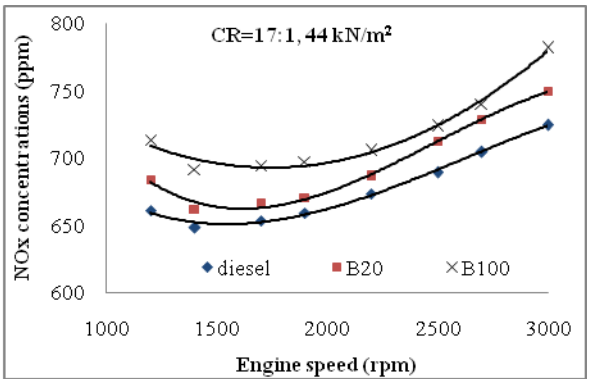

Fig. (20). Engine speed effect on NOx concentrations at constant load for the tested fuels.

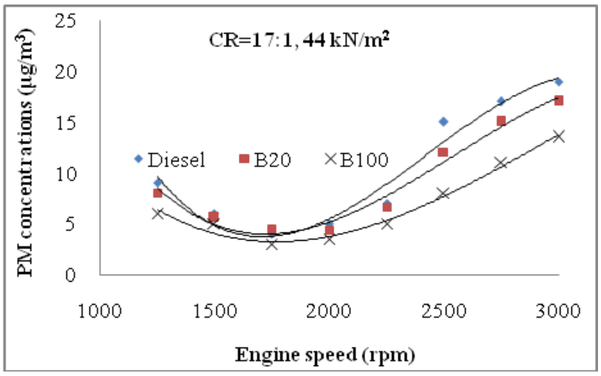

Fig. (21). Engine speed effect on PM concentrations at constant load for the tested fuels.

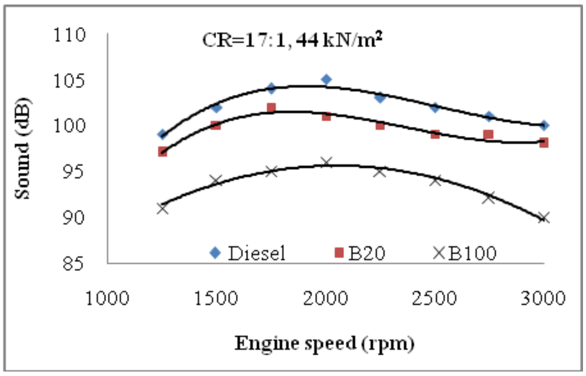

Fig. (22). Engine speed effect on engine noise at constant load for the tested fuels.