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Performance of Diesel Engine Fuelled by a Biodiesel Extracted From A Waste Cocking Oil

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Abstract

In this study, the combustion characteristics and emissions of compression ignition diesel engine were measured using a biodiesel as an alternative fuel. The tests were performed in Chemical and Mechanical Engineering department laboratories at steady state conditions for a four stroke single cylinder diesel engine loaded at variable engine speed between 1200-2600 rpm. The waste vegetable oil (cocking oil) used in this investigation transferred from Tafila Technical University restaurant collected and disposed in a suitable way. The testing results show without any modification to diesel engine, under all conditions dynamical performance kept normal, and the B20, B5 blend fuels (include 20%, 5% biodiesel respectively) led to satisfactory emissions at variable load. The experimental results compared with standard diesel show that biodiesel provided significant reductions in CO, and unburned HC, but the NOx was increased. Biodiesel has a 5.95 % increasing in brake-specific fuel consumption due to its lower heating value. However, using B20 and B5 diesel fuel gave better emission results, NOx and brake-specific fuel consumption.

The experimental results show that the fuel consumption rate, brake thermal efficiency, and exhaust gas temperature increased while the bsfc, emission indices of CO_2, CO decreased with an increase of engine speed. Moreover, the engine power increased when increasing the biodiesel percentage varied from 1.23 to 3.2 for standard diesel while for B20 between 1.5 to 3.47.while brake specific energy consumption varied between 16.8 to 13.81 MJ/kW.kg for standard diesel, but for B5 found to be between 16.3 to 13 MJ/kW.kg. In particular, biodiesel produced with the addition of the peroxidation process had the lowest equivalence ratio and emission indices of CO_2, CO. The emission of NOx among all of the test fuels found to be increased when using B5 and B20 instead of standard diesel and these results validate the data recorded by other previous work. Therefore, the peroxidation process can be used effectively to improve the fuel properties and reduce emissions when biodiesel is used.

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Key words: Biodiesel; Emissions; Performance; cooking oil; Brake Power; Fatty Acid

Nomenclature

Bhp: Brake horse power.	hp
BSFC: the brake specific fuel consumption.	Kg / KW .hr
BTE: brake thermal efficiency.	
BP: Brake power.	kW
CN: Cetane number.	
CV: Caloric value.	KJ/Kg
CO: Carbon monoxide.	
CO2: carbon dioxide.	
DI: diesel engine	
DOC: diesel oxidation catalyst.	
EGT: exhaust gas temperature.	°C
FAME: fatty acid methyl esters.	
FP: Frictional power.	
GNP: Gross national product	
HC: hydrocarbons.	
IP: Indicate power.	
m: fuel mass.	Kg
$\dot{m}f$: mass flow rate .	Kg /hr
NOx: Nitrogen Oxides	
PM: particulate matter.	
SFC: specific fuel consumption	kg/hr
TDC: top dead centre	
T: torque.	N.m
t : time.	sec
Vf: fuel volume.	m^3
WCO : Waste cooking oils.	
e:energy .	KJ
$\dot{e}$: Energy consumption.	KJ/hr

Greek Symbols

ρ : fuel density .	Kg /m^3
μ: Dynamic Viscosity	(kg/m.s)
η: efficiency	
ω : angular speed.	rad / sec

Subscripts

g: gas

l: liquid

1- Introduction

Jordan is totally dependent on imported crude oil and petroleum products to meet all its energy requirements shown in figure 1 where the demand increased from one year to another. The daily petroleum consumption is around 100000 bbl /day, which is a significant load on the GNP and the development of Jordan's economy [ ].

Recent studies show that oil is the main source of energy for many countries. One of the key elements of Jordan's energy strategy is to diversify its energy supply sources to meet the energy need in next decades of the twenty first century since the oil issue made many policy conflicts between the countries during the last ten years where the oil price increased continuously. So it is very important for all countries, especially that non producing oil country.
The depletion of world petroleum reserves and increased environmental concerns has stimulated recent interest in alternative sources for petroleum based fuel.

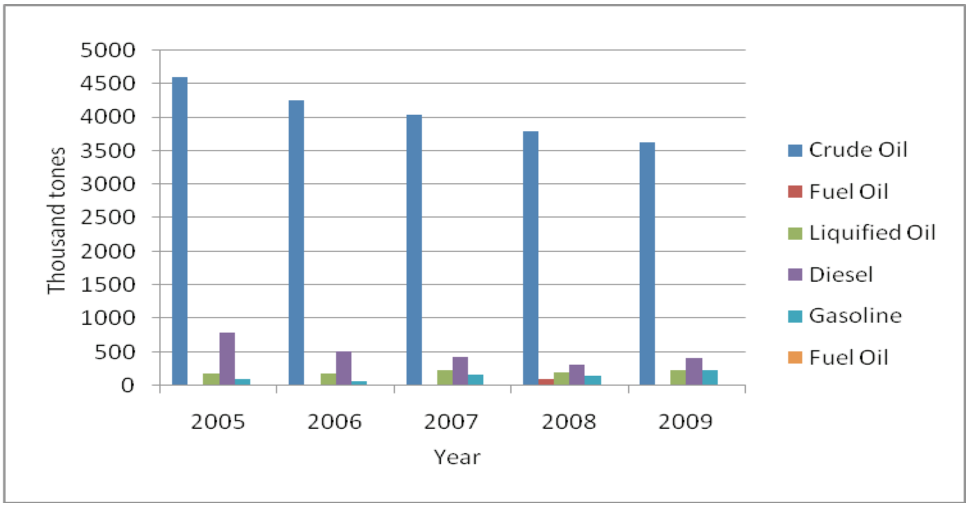

Figure1.Imported crude oil and oil products during the period 2005-2009 in Jordan (000 metric tons).

Diesel engines are widely used as power sources in medium and heavy-duty applications because of their lower fuel consumption and lower emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) compared with gasoline engines. Rudolf Diesel, the inventor of the diesel engine, ran an engine on groundnut oil at the Paris Exposition of 1900. Since then, vegetable oils have been used as fuels when petroleum supplies were expensive or difficult to obtain. With the increased availability of petroleum in the 1940s, research into vegetable oils decreased. Since the oil crisis of the 1970s research interest has expanded in the area of alternative fuels [ ].
Biodiesel is produced from fatty acids triglycerides and can be used in diesel engines without serious problems. Some other types of vegetable oils, such as sunflower oil, corn oil and olive oil, that are abundant in many areas, along with some wastes, such as used frying oils and animal fats, appear to be attractive for biodiesel production [ ]. The strong advantage on the use of fatty (FAME) biodiesel is the fact that independently on the raw material used for their production, the addition of biodiesel in petroleum derived fuels improves the emissions of PM which comprises a serious disadvantage of the diesel engine, especially in polluted areas such as the Mediterranean sea. Vegetable oils have become more. The cost of vegetable oils, however, is the main handicap to commercialization of the product [3]. Also, several chemical properties of oils, among them are the high viscosity and high molecular weight,

cause poor fuel atomization and low volatility, leading to incomplete combustion and severe engine deposits, injector coking and piston ring sticking [4]. Improving the viscosity of vegetable oil by blending, pyrolysis and emulsification does not solve the problem completely. Research has shown that one way to improve the fuel properties of oils and fats is their transesterification [5, 6]. Transesterification is a process of converting vegetable oil into biodiesel fuel. This process supplies a fuel that can be operated in unmodified diesel engines [7]. Numerous vegetable oil esters have been tried as alternative to diesel fuel. A lot of researchers have reported that with the use of vegetable oil ester as a fuel in diesel engines, a diminution in harmful exhaust emissions as well as equivalent engine performance with diesel fuel were achieved [8–17]. Several studies have found that biodiesel seems to emit lower pollutants than standard diesel fuel. decreasing of carbon dioxide (CO_2) by using biodiesel contributes to reduce greenhouse effect. In other sense, diminishing of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx).

Although biodiesel has many advantages when it comes to fuel properties, it still has several properties that need to be improved, such as its lower calorific value, lower horsepower output, and its comparatively higher emission of nitrogen oxides. Monyem et al. [7] believed that fuel properties of biodiesel might be affected by oxidation after the biodiesel was stored for a period of time.

The most available works have been conducted the performance and characteristics of biodiesel on the engine behavior and environment, Agarwal, and Das [1] , Bagby[2] used Seed oils for diesel fuels sources and properties, Canakci, and Gerpen[3], Dimitrios et al [4]. Monyem [5] . The effect of biodiesel oxidation on engine performance and emissions , McDonnell et al [7] ,Peterson [8] Vegetable oil as a diesel fuel: status and research Prioriti, Can et al [9] . characteristics of a low heat rejection diesel engine operating with biodiesel , Pramanik, [11] . Properties and use of jatropha oil and diesel fuel blends in compression ignition engine, Singh et al [13] Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel, Cherng et al [14]. Diesel engine performance and emission characteristics of biodiesel produced by the per oxidation process, Hill et al [16] Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels ,Pimentel and , Patzek[17]. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower has been conducted . Carraretto et al [19], studied the biodiesel as alternative fuel: experimental analysis and energetic evaluations, by operation of a biodiesel fuelled boiler has been checked for same months. ,Mustafa Canakci,[5] 2006, Conducted the combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel, Raheman and Ghadge,[ ], investigated the performance of diesel engine with Biodiesel at varying compression ratio and ignition timing. Ming Zheng et al [ ], carried out the effect of biodiesel engine performance and emissions in low temperature combustion Xiangmei [12].

Can et al [9] they studied the performance characteristics of a low heat rejection diesel engine operating with biodiesel, ,Magın et al [20] The use of biofuels which is being made by most governments following international energy policies is presently finding some resistance from car and components manufacturing companies, private users and local administrations ,Gumus and Kasifoglub [10] , 2010. studied apricot seed kernel oil was transesterified with methanol using potassium hydroxide as catalyst to obtain apricot seed kernel oil methyl ester, Zhu et al [18]

The study aims to investigate the effects of the blended fuels on reducing NOx and particulate.

2- Objectives:

The main objective of this study was to characterize the effect of biodiesel properties on the combustion characteristics, performance and exhaust emissions of a diesel engine. The performance, emissions and combustion characteristics of the engine fueled with biodiesel from a waste cocking vegetable oil that is available in Tafila Technical University restaurants.

3- Theoretical Background

The engine that used in this experiment is single cylinder compression ignition engine (diesel engine) to observing the effect of adding biodiesel to the engine performance characteristic.
In compression ignition engines air alone is induced into the cylinder, the fuel is injected directly into the engine cylinder just before the combustion process is required.
The air fuel mixture in the combustion chamber is ignite when it reaches the self ignition temperature by this type of ignition no external spark needed, the air fuel mixture is ignite by using high pressure to reach the self ignition temperature.
The brake power and torque is related to each other with respect to the engine speed this relation gives an indicate to the load that the engine can take over certain engine speed which that translated in the form of torque at the crank shaft measured by the dynamometer. According to the available measurement instruments the brake power is taken as reference to the experiment.
The fuel consumption is another characteristic using in engine tests, the fuel consumption is measured as flow rate _ mass flow per unit time, usually the volume flow rate is given according to measure the consumed fuel volume per unit time according to the relation;

$$\dot{V}f = \frac{Vf}{t} \quad \ldots\ldots(1)$$

Note that the fuel density is relating the fuel volume to the fuel mass by the relation;

$$\dot{m}f = \dot{V}f.\rho f \quad \ldots\ldots(2)$$

$$\dot{m}f = \frac{Vf.\rho f}{t} \quad \ldots\ldots(3)$$

A more useful parameter is specific fuel consumption (sfc) which defined as the fuel flow rate per unit output power. It measures how efficiently an engine is using the fuel supplied to produce work

$$sfc = \frac{\dot{m}f}{P} \quad \ldots\ldots(4)$$

In the case that the brake power is taken as a reference then the brake specific fuel consumption (bsfc).

$$BSFC = \frac{\dot{m}f}{BP} \quad \ldots\ldots(5)$$

The other important aspect of using biodiesel to operate the compression ignition engines is to reduce emissions, to study the effect of adding biodiesel on the input energy needed to produce a certain brake power , the term brake specific energy consumption (bsec) is used, which defined as the amount of input energy required to develop one kilowatt of power .

The (bsec) is important parameter to the engine, because it takes care of both mass flow rate and heating value of the fuel, the following relations can be used to estimate the Bsfc

$$e = \dot{m}f.CV \quad \ldots\ldots(6)$$

$$b\sec = \frac{e}{BP} \qquad (7)$$

The main aims of this work to reduce the emissions emerged from the engines, whenever the levels of emission of oxides of nitrogen (nitric oxide NO and nitrogen dioxide NO_2, usually grouped together as NOx),carbon monoxide (CO),unburned hydrocarbons (HC) are important engine operating characteristics.

The concentration of gaseous emissions in the engine exhaust gases are usually measured in parts per million or percent by the volume (which corresponds to the mole fraction multiplied by 1000,000 or by 100, respectively).

There are many indicators of emission levels ,the specific emissions is one of it, which is defined as the mass flow rate of the pollutant of unit power output, in case of brake power the brake specific emissions term is used as:

$$BsNOx = \frac{mNOx}{BP} \qquad (8)$$

$$BsHC = \frac{mHC}{BP} \qquad (9)$$

$$BsCO = \frac{mCO}{BP} \qquad (10)$$

Similar expressions for other pollutants, the unit that commonly used to identify the brake specific emissions is g / KW.

5- Experimental Investigation

5.1 Production of Biodiesel

Waste Sunflower oil was selected to produce the biodiesel. The biodiesel production method is shown in Fig 2, where 5.5 Grams potassium hydroxide (KOH) and 100 methyl alcohol (CH_3OH) were used for esterification of 250ml of Sunflower oil. The catalyst was dissolved in the alcohol then the alcohol–catalyst mixture was poured into the sunflower oil as shown in figure 3. The mixture was heated and mixed meanwhile. The temperature and the mixing speed of the sunflower oil, alcohol and catalyst mixture was kept constant (60 °C and 1250 rpm) during the esterification as shown figure 4. When the transesterification was finished the mixture was taken to a tank to be settled. After the settlement of the biodiesel and the glycerin, the biodiesel washed for 12 h with pure water to remove alcohol and catalyst residue. When the washing process was completed, it must be waited until biodiesel and water were separated into two different phases. Then the water was drained. To eliminate the water in the biodiesel which remains from washing, it was dried by heating it up to 100 C for half an hour. The water in the biodiesel was evaporated during the drying process.

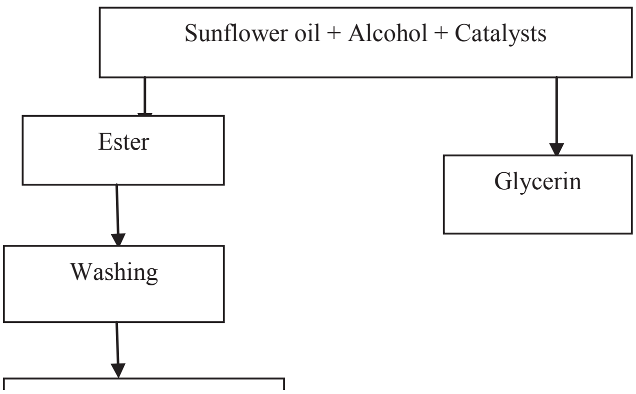

Figure2. Biodiesel production method

Figure3.Solving the catalyst mixture in oil (60 °C 1250 rpm)

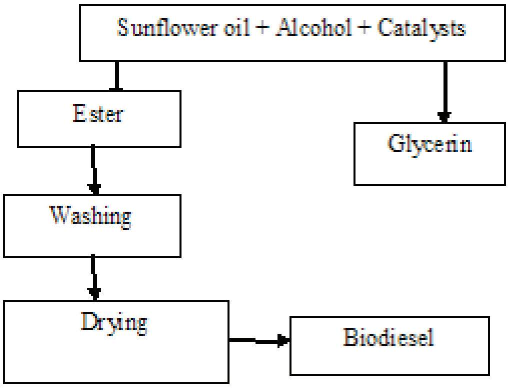

Figure4. Heating the overall mixture for an hour.

5.2. Experimental Procedure and Measurements

The performance of biodiesel and its blends (B5, and B20) were studied in comparison with diesel fuel. The biodiesel is mixing with the standard diesel in an external tank, according to the needed ratio which is in this case 5% biodiesel with 95% standard diesel, 20% biodiesel with 80% standard diesel.
The compression ignition engine used for the study was a single cylinder, four stroke, direct injection, air-cooled engine. The schematic of the test system is shown in figure4.4. The most important engine specifications are given in Table 4.1. The engine was coupled with an electric dynamometer to apply different engine loads. The engine was started on neat diesel fuel and warmed up. Then parameters like the speed of operation, fuel consumption and load were measured. After the engine reached the stabilized working condition, emissions were measured using an exhaust gas analyzer. Each reading was repeated to obtain a mean value. The engine performance and exhaust emissions were studied at different engine loads and constant engine speed, 2400 rpm obtained maximum torque. The following measurements and test performance data for the engine performance were tabulated as shown below in tables 1,2 and 3.

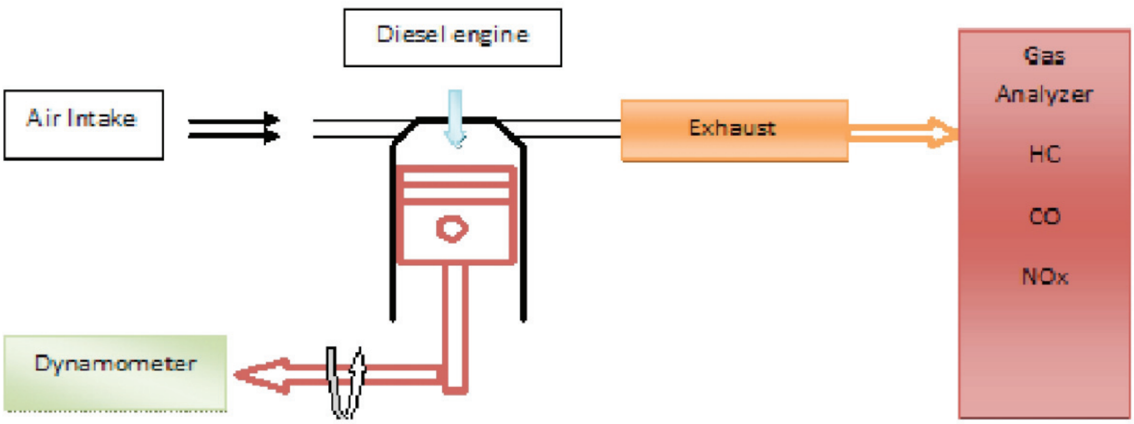

Figure5. Schematic of the test system.

Table.1. Variation of BSEC with respect to brake power

Table 2. Variation of engine power with engine speed at B5% and 20%

Brake power (KW)	**Brake specific energy consumption (MJ/KW.hr)**		
	diesel	**B5%**	**B20%**
1.5	16.8	16.3	15.8
2	14.1	13.93	13.2
2.5	12.6	12.59	12.15
3	12.4	12.23	11.78
3.5	12.04	11.92	11.42
4	12.84	12.41	12.17
4.5	13.81	13	12.72

Table3. Variation of CO with respect to brake power.

Speed (rpm)	Engine power (KW)		
	diesel	B5%	B20%
1200	1.3	1.2	1.5
1400	1.53	1.53	1.8
1600	2	2.12	2.28
1800	2.53	2.8	3
1900	3.25	3.4	3.55
2000	3.8	4.05	4.17
2200	4.25	4.31	4.49
2600	3.2	3.35	3.47

Brake power (KW)	CO%		
	DESIEL	**B5%**	**B20%**
1.5	0.073	0.061	0.054
2	0.08	0.069	0.065
2.5	0.096	0.077	0.073
3	0.11	0.092	0.078
3.5	0.12	0.11	0.088
4	0.16	0.13	0.1
4.5	0.18	0.16	0.12

6- Results and Discussion:

The engine power variation with respect to engine speed at full load is presented in Figure 6. As it is shown in the figure, the power initially increases with increasing of engine speed until it reaches a maximum value and then decreases with further increasing engine speed. At the same time, engine power has the same trend according to addition of biodiesel content in the blend. The power initially increases with the addition of biodiesel content in the blend, reaches a maximum value and then decreases with more increase of the biodiesel content. Although addition of the biodiesel to the diesel fuel decreases its heating value, higher power was obtained in the experiments. There are a number of causes for this. Firstly, the biodiesel includes approximately 10% (in weight) oxygen that can be used in combustion, especially in the fuel rich zone. This is a possible reason for more complete combustion, thereby increasing the torque and power. Second, the diesel fuel is pumped to the diesel engine cylinder on a volumetric basis and the density of the biodiesel blend is higher than that of diesel fuel. Therefore, a larger mass flow rate for the same fuel volume is pumped to the engine, resulting in the increase in torque and power. Meanwhile, the more viscous blend means the less internal leakage in the fuel pump is seen. Again, this results in an increase in the torque and power. The power increases with the addition of biodiesel content in the blend until the B20 blend and reaches a maximum value (4.49 kW), when the biodiesel content continues to increase in the blend, the power will decrease below that of the diesel fuel (4.25 kW).

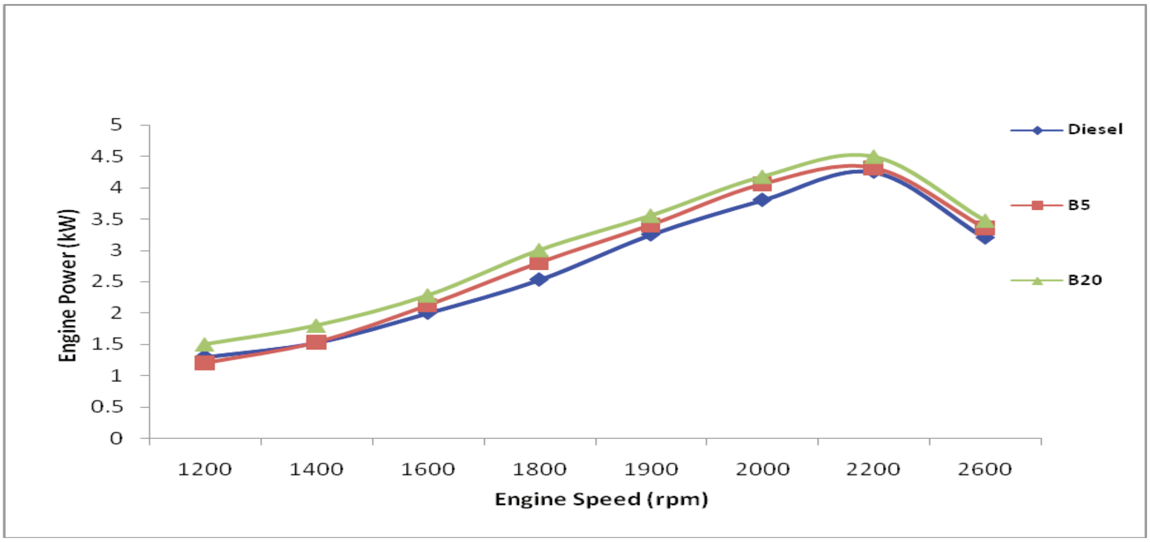

Figure 6. Variation of engine power versus engine speed.

Brake specific energy consumption (BSEC) measures the amount of input energy required to develop one-kilowatt power. The BSEC is an important parameter of an engine because it takes care of both mass flow rate and heating value of the fuel. As shown in Figure7. The BSEC initially decreases with increasing of engine load until it reaches a maximum value and then increases slightly with further increasing engine load for all kind of fuels. According to addition of biodiesel content in the blend, the BSEC initially decreases until it reaches a maximum value at B20 blend and then increases with more increase of the biodiesel content in blend. In the using of blends B5 and B20, the BSEC of the engine is lower than that of diesel for all loads for the reason that, biodiesel includes oxygen which improves combustion of fuel.

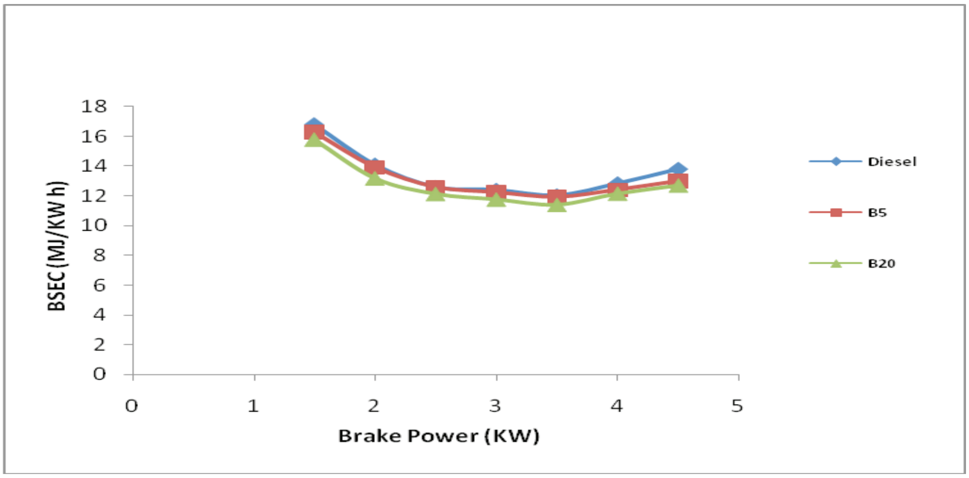

Figure7. Variation of BSEC with brake power.

Figure8 shows the variation of the percentage of carbon monoxide (CO) emission for the diesel fuel, B5%, and B20%, operated at the rated engine speed of 2200 rpm under various load conditions. The CO emissions are found to be increasing with increase in load since the air–fuel ratio decreases with increase in load such as all typical internal combustion engines. The engine emits less CO using less percentage of biodiesel as compared to that of diesel fuel under all loading conditions. With increasing biodiesel percentage, CO emission level decreases for the reason that a mount of oxygen content in biodiesel helps for the complete combustion.

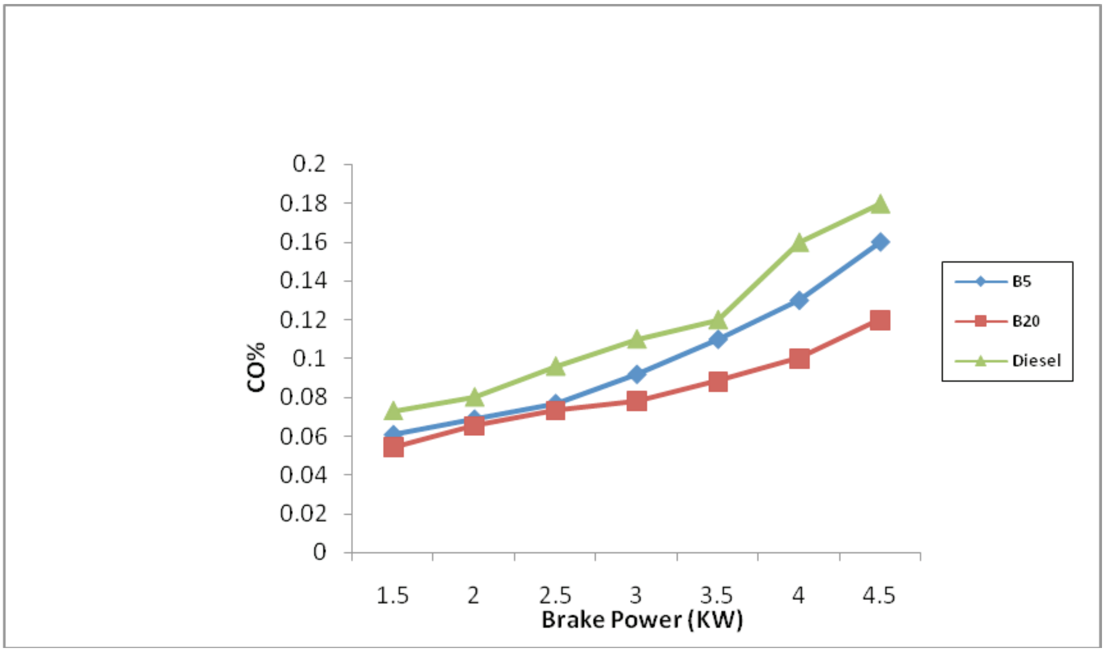

Figure8. Variation of CO with respect to brake power.

The variation of hydrocarbon (HC) emission with load for different fuels tested is plotted in Figure 9. The HC emissions increase with increasing in load. HC emissions decreases with increasing biodiesel percentage in the blend. This decreasing may be explained with the oxygen content in biodiesel improve the quality of combustion.

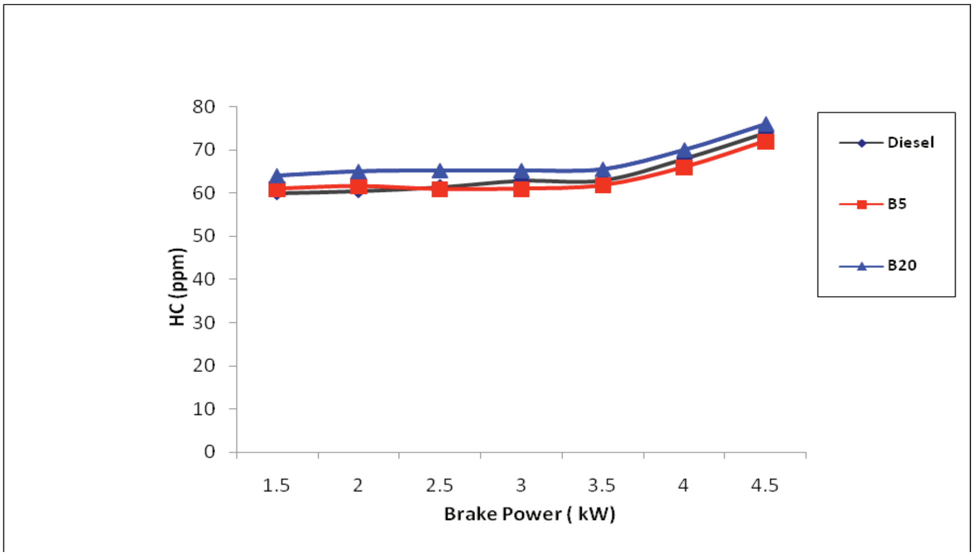

Figure 9. variation of HC with respect to brake power.

The variation of Nitrogen oxides (NOx) with brake power shown in figure 10. The NOx emission for biodiesel is higher than that of the diesel oil. The NOx emission increases with increasing of biodiesel include in the blends and reaches

Maximum value with using B20% as fuel. Nitrogen oxides are reported by several researchers to be increased with biodiesel . The emission of NOx is determined by oxygen concentration, peak pressure, combustion temperature and time. The availability of oxygen in biodiesel can explain the increase in the NOx emission, since additional oxygen for NOx formation may be provided by the fuel oxygen.

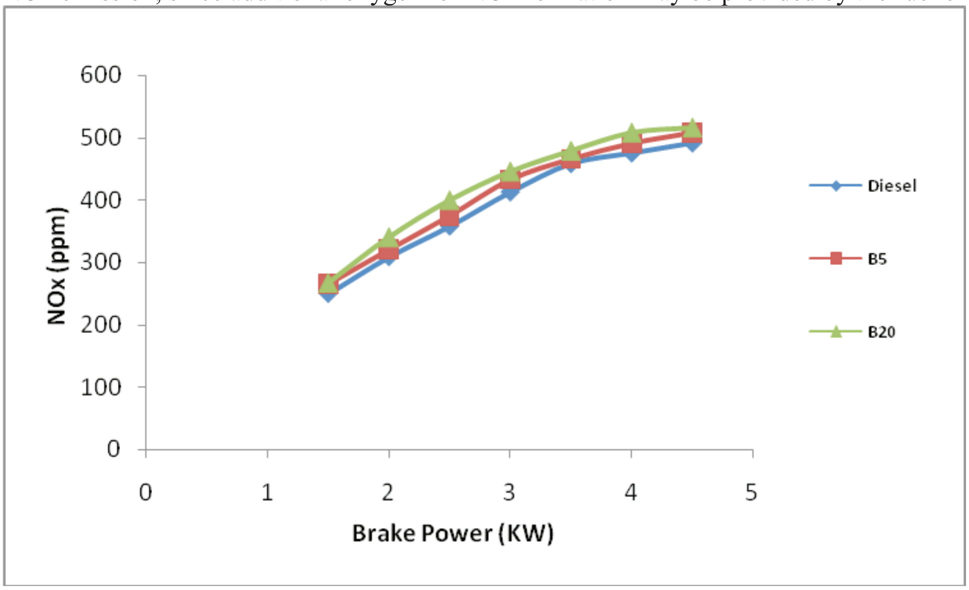

Figure10. Variation of NOx with respect to brake power.

Some General results

1- The characteristics of Biodiesel are close to diesel fuels, and therefore Biodiesel becomes a strong source to replace the diesel fuels.

2- The conversion of triglycerides into methyl or ethyl esters through the transesterification process, reduces the molecular weight to one-third that of the triglyceride and also reduces the viscosity by a factor of about eight and increases the volatility
Marginally.

3- Biodiesel has viscosity close to diesel fuels. These esters contain 10–11% oxygen by weight, which may encourage more combustion than hydrocarbon-based diesel fuels in an engine. The cetane number of Biodiesel is around 50. The use of tertiary fatty amines and amides can be effective in enhancing the ignition quality of the finished diesel fuel without having any negative effect on its cold flow properties. Since the volatility
increases marginally, the starting problem persists in cold conditions.

4- Biodiesel is considered clean fuel it has no sulphur no aromatics and has about 10% built in oxygen, which helps it to burn fully its higher cetane number improves the ignition quality even when blended in the petroleum diesel. It is a general property of hydrocarbons that the auto-ignition temperature is higher for more volatile hydrocarbons. Therefore, the less volatile middle distillate fractions of crude oil boiling in the range of 250–370 °C are suitable as diesel fuels.

Biodiesel effects on engine emissions

Effect on NOx emissions: Many studies have been done to study the effect of the
biodiesel on NOx emissions. Most of them agree that generally biodiesel increases NOx emissions. Unfortunately, the reasons argued are not as clear as the conclusions obtained. The most commonly accepted justification for this behavior lies in the
higher cetane number of the biodiesel that reduces the ignition delay. Reducing ignition delay increases NOx emissions since the residence time of the burning mixture in the cylinder increases]. Other reason for the increase of NOx emissions when the engine works with biodiesel is that due to the improved combustion that produces less HC, CO and smoke, the temperature increases, besides the higher amount of oxygen present in the combustion chamber leads to an increase in NOx emissions [1]. Finally, there are other theories that point the importance of the radioactive heat transfer fro soot in the combustion chamber. According to this last hypothesis soot radiation may reduce NOx emissions, since biodiesel produces less soot an undesirable increase on NOx is
obtained.

The particulate emission reduction and specifically the reduction in soot emissions become one of the most important advantages of biodiesel. This reduction is mainly
produced by oxygenated compounds contained in biodiesel. Oxygen contained in fuel contributes to an increase of the local oxygen–fuel ratio during combustion. In addition, the lack of aromatic hydrocarbons and sulphur compounds further contribute to particulate emissions reduction since these compounds increase the soot nucleation rate.

7- Conclusions

1) Biodiesel is an alternative fuel that is cleaner than petrodiesel. Biodiesel can be used directly as fuel for a diesel engine without having to modify the engine system. It has the major advantages of having high biodegradability, excellent lubricity and no sulfur content

1) Waste vegetable oil was found to be safe and efficient alternative fuel and has a low impact on the environment

3) As the B20 produced significant reductions in the CO, HC, and smoke emissions compared with standard diesel and B5.

4) The biodiesel increased volumetric fuel consumption due to its chemically bound oxygen content. In contrast the petroleum derived fuels showed about the same consumption results. Overall, vegetable oil is an attractive alternative for diesel fuel in the frame of Single Fuel Policy.

5) Different blends with diesel fuel were used as fuel in a compression ignition engine and its performance and emission characteristics were analyzed. Lower percent of blends (B5, B20) give a good improvement in the engine power. Lower percent of blends also reduced BSEC. Furthermore they were found to improve exhaust emissions.

6) Biodiesel can be used safely in the diesel engine, at least in small blending ratios with normal diesel fuel.

7) The fuel consumption increases as the biodiesel content in the fuel rises due to its lower heating power. Nevertheless, it should be noted that the biodiesel maintains approximately the same engine efficiency at that obtained with diesel fuel.

8) Increasing the biodiesel content reduces the particulates in the engine exhaust prior to the after-treatment. The engine after-treatment reduces particulate emissions drastically, hiding the potential benefits of biodiesel.

9) Regarding NOx emissions the results obtained in this study1 show that the higher the biodiesel content, the higher the NOx emissions. In addition, it should be underlined that the effect of the fuel composition is less important than the effect of the EGR reduction due to the lower heating power of biodiesel.

10) The increase in engine speed caused an increase in fuel consumption rate, brake thermal efficiency, equivalence ratio, and exhaust gas temperature, while at the same time decreasing the bsfc, emission indices of CO_2, CO and the NOx for the four fuelS.

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