

# Study on Combustion Performance of Diesel Engine Fueled by Synthesized Waste Cooking Oil Biodiesel Blends

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## Abstract

The waste cooking oil or used cooking oil is the best source of biodiesel synthesizing because it enters into the so-called W2E field, whereas not only get rid of the used cooking oils, but produce energy from waste fuel. In this study, biodiesel was synthesized from the used cooking oil and specifications are tested. From 1 liter of used cooking oil, 940 ml is gained. The remaining of liter is glycerine and water. A Blend of 20% of biodiesel with 80% of net diesel by volume is formed. Blends of 100% diesel and 100% biodiesel are prepared too. The diesel engine combustion performance is studied. Brake thermal efficiency, brake specific fuel consumption, volumetric efficiency, mean effective pressure, and engine outlet temperature. Cylinder pressure variation with crank angle is analyzed. At last not least, the concentrations of hydrocarbon and nitrogen pollutants are measured. The results showed a significant enhancement in engine power and pollutant gases emitted. There is positive compatible with other critical researches.

**Keywords :-** Waste cooking oil, Synthesizing, Biodiesel blends, Energy, Combustion performance.

## الخلاصة

يعتبر زيت الطبخ المستعمل من مصادر تكوين البايوديزل المفيدة جدا لانها تدخل في مجال ما يعرف بـ W2E حيث اننا ليس فقط نتخلص من زيوت الطبخ المستعملة و انما ننتج من النفايات وقود. في هذا البحث، تم تحضير البايوديزل من زيت الطعام المستعمل و اختبارها لتثبيت مواصفاته. من واحد لتر للزيت المستعمل حصلنا على 940 مليلتر من البايوديزل و الباقي كلسيرين و ماء. ثم تم خلط هذا البايوديزل مع الديزل بنسبه 20% من البايوديزل مع 80% من الديزل. و تشغيل محرك الديزل عنده و كما عند نسبه 100% ديزل و 100 بايوديزل. حيث تم دراسته كفاءة الاحتراق من خلال الكفاءة المكبجه و متوسط الضغط المكبجي و معدل صرف الوقود المكبجي و الكفاءه الحجميه للهواء الداخل للمحرك و العلاقه بين ضغط الاسطوانه و زاويه دوران عمود المرفق. كما ان تركيز الملوثات الكربونيه و النتروجينيه و درجه حرارة العادم تم تحليلها. اظهرت النتائج تطابق كبير مع البحوث الاخرى و كانت ايجابيه.

**الكلمات المفتاحيه :-** زيت الطعام المستعمل ، تصنيع ، خليط البايوديزل، الطاقه ، خصائص الاحتراق .

## Introduction

Energy, affairs and demand remain the 21st century wide title and its mover for the advancement of technology and the promotion of peoples. Still, the fossil fuel is the most competitive energy source but its depletion energy. The challenges of diesel engines emissions, which affect the ozone layer and initiated global warming are the other axis in the importance of alternative energy and the needing to find clean and sustainable energy. ( **The global energy statistical yearbook , 2015** ) . Diesel engines have essential things made it the first choice in the world of engines such as: more desirable and most fuel-efficient engines but most polluting engine as well. Research and studies have been accelerated to find alternative fuels for conventional diesel. Biodiesel, bio alcohols, bio gases and hydrogen have all proved that they can be used instead of diesel in part or in whole in diesel engine combustion chamber without major modification in engine design as in the researches of ( **Sangamesh and Navindgi , 2016 ; Knothe and Steidly , 2015 ; and Jinlin et.al., 2011**).

(**Gertz , 2000 ; Choe and Min , 2009; Aladedunyia et.al., 2009**) studied the oil, fat, greases that might be transferred to be a biodiesel. The chemistry of those fats and the control on them are studied too. Biodiesel is one of the biodegradable and

promising alternative fuels. All kinds of oils, greases, and fats from plants or animals are the source of the composition of the biodiesel. As a result of the high demand for oils that enter human food, the UN has banned the use of these types of oils in the research of bio diesel production ( **Rakib *et.al.*, 2013** ). In critical literature, there are numerous efforts to prepare, produce, synthesize, manufacture of biodiesel from different bio sources and waste cooking oil on of them as in ( **Carlos *et.al.*, 2011** ; **William *et.al.*, 2013** ) The transesterification process is happening with different techniques and methods and all are depending on the catalyst, alcohol, and temperature of oil. ( **Carlos *et.al.*, 2013** ).

The research of testing the performance of diesel engine fueled by biodiesel can be divided as the following: research of using biodiesel and biodiesel blends with net diesel such as in work of **Muhammad *et.al.*, 2017**; **Nitin *et.al.*, 2012** ; **Srinivasa, 2016**). Research of using biodiesel- diesel blends along with alcohol like ethanol in work of **Shiyasharan and Nitin , 2016** ; **Sandra *et.al.*, 2014** ; **Syed *et.al.*, 2009**). Hence, research of biodiesel-diesel blends in combining with bio gases such as methane or CNG..etc. is presented by work of **Fernando *et.al.*, 2013** . The efforts to utilized the biodiesel – diesel blends along with hydrogen as in work of ( **Rajshekhhar *et.al.*, 2015** ).

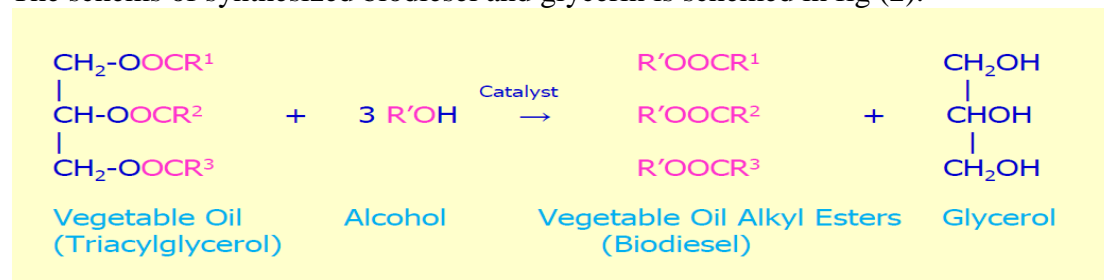
In this work, biodiesel is synthesized from waste cooking oil, the restraints filtered are provided the used cooking oil. From reacts of one liter of used cooking oil, 940 ml are produced while the remained is glycerine and othe impurities. The economic benefit is calculated. The synthesized biodiesel is tested to recognise its chemical and physical properties. To study the compression ignition engine performances, engine is investigated experimentally. The combustion performance is studied in two ways, first by found the brake thermal efficiency, brake specific fuel consumption, volumetric efficiency, and mean effective pressure. Second way by analyzing the outlet emission gases constituents. A sophisticated results are obtained and good compatible in the results are observed as compared with critical literatures.

## Experimental Work

### 1- The Synthesize Of Biodiesel

Most of critical literature described the techniques and methods of biodiesel synthesizing. Also, The author has efforts in this field, ( **Duraïd *et.al.*, 2008** ). Transesterification process is mainly depending on: the catalyst type and amount, the alcohol type and amount, the temperature of oil at reaction time.

In this work, the optimum amounts of catalyst, alcohol, and oil temperature are identified. In glass beaker 1 litre of refined waste cooking oil is heated and maintained at 60 °C. In another glass beaker 4 gramm of NaOH are solved in 130 ml of alcohol. The transesterification reaction started when the solution of NaOH added to hot oil and stirred for one hour. The mixture is left for 24 hours. The biodiesel is separated from glycerin by gravity. The transesterification reaction shows by fig. (1). The scheme of synthesized biodiesel and glycerin is schemed in fig (2).



**Fig. (1) The transesterification reaction**



**Fig (2) The Schemes of Synthesized Biodiesel and glycerin**

The synthesised biodiesel is tested to get its index of fuel. Table (1) represents the synthesized biodiesel fuel index.

**Table (1) The fuel index of waste cooking oil, its biodiesel, and diesel.**

Property	Waste oil	Synthesis biodiesel	Diesel (Talwadel and Navindgi]
Density ( $\text{kg/m}^3$ ) at 15 °C	931	897	840
Viscosity ( $\text{mm}^2/\text{sec}$ ) at 40°C	26.40	5.08	1.9 ~ 2.3
Cetane number	49	54	40~45
Flash point (K)	509	438	340
Pour point (K)	-15	-6	4.4
Net caloric value (MJ/kg)	33.15	35.67	43.5

As a promising fuel, biodiesel might solve the global shortage in traditional diesel and solve green house issues, the economy of biodiesel synthesized has important attention. In this research full cost calculation is made. All prices are shifted to US \$ for comparison. Table (2) illustrates the synthesized biodiesel feasibility which mentioned that one liter of synthesized biodiesel is less price as a compare with local price of diesel. The results showed that biodiesel is less price than diesel price.

**Table (2) The synthesized biodiesel feasibility**

No.	Subject	Quantity	Price US \$ per litre
1-	Waste cooking oil	1 litre	Zero
2-	Catalist (NaOH)	4 gram	0.05
3-	Methanol	130 mlitre	0.1
4-	Operation	-	0.05
		Total	<b>0.2</b>

## 2- Combustion Performance Utilization

The performance experiments to check synthesized biodiesel combustion are carried out. Biodiesel is blended with net diesel as D100, B20, and B100. It represents net diesel 80% diesel and 20% biodiesel, 100% biodiesel by volume respectively. The combustion performance of biodiesel – diesel blends are tested in experimental setup which contains two parts: single cylinder compression ignition engine and data Acquesting for measuring. Table (3) shows the experimental engine details.

In internal combustion laboratory- department of mechanical engineering / university of Babylon, single cylinder compression ignition engine is fixed on a suitable chaise with all electrical, cooling, and lubricating connections. Engine is joined to electrical dynamometer to measure its output brake power and to control and measure the load of engine. Suitable flow meters are used to measure engine intake air amount and fuel consumption amount as a function of time (rate). Pressure transducer is connected to high speed data logger to give the combustion chamber pressure distribution along with crank angle decoder which used to measure the crank angle. Tachometer is utilized to find engine speed. K type thermo couples are used to find the temperatures at different positions on engine. In addition to this, multi gas analyzer is adopted to measure the mono carbon oxides, unburned hydrocarbon, dioxide carbon, and nitrogen oxides that emitted in outlet engine exhaust gases.

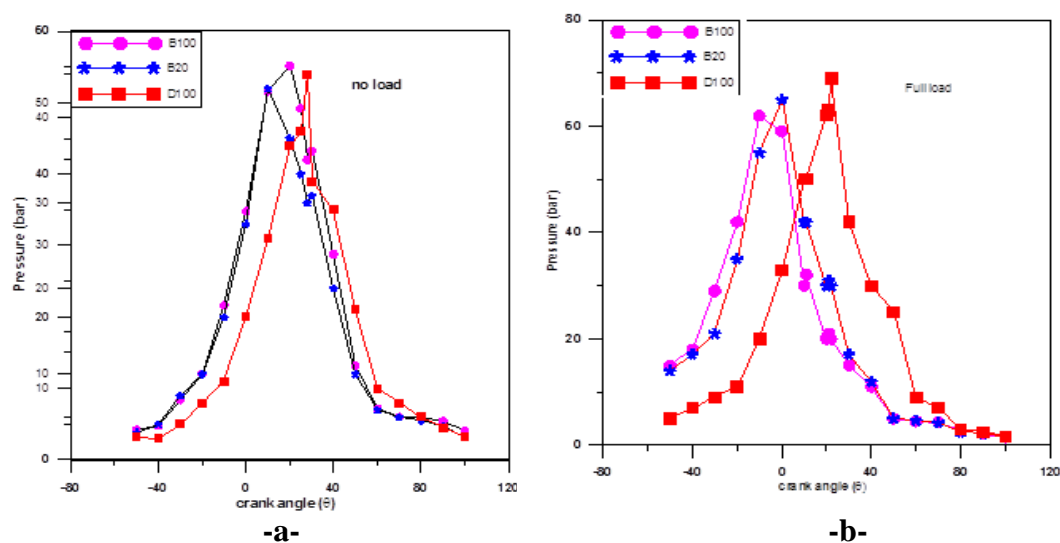
## Results And Discussion

Tested of combustion performances are divided in two parts, engine thermal characteristic analyzing and find out the emission constituent ratios.

Fig (3) represents the variation of cylinder pressure vs. crank angle in full load and no load at different blend ratio. At no load and full load, it is observed that peak pressures of B20 and B100 are advanced than the peak pressure of D100 by 8 to 10 degrees. At full load, this trend is noticed clearly. This combustion behaviour means that the blends of biodiesel-diesel enhanced the combustion performance process and the power stroke is becoming more long to give enough time to convert most of producing thermal power to break power.

**Table (3) The diesel engine details**

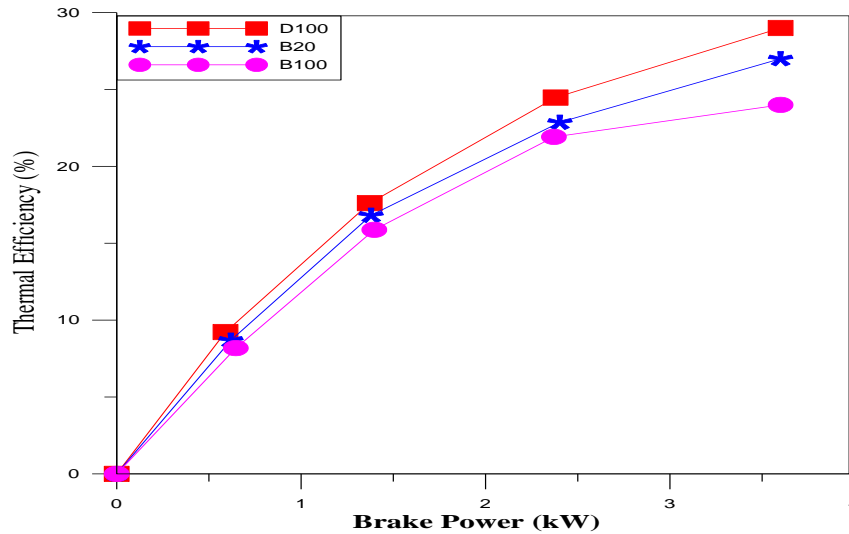
<b>Make</b>	Kirloskar AV-1
<b>Type</b>	Vertical, single cylinder, cooling by water, DI
<b>Bore, stroke</b>	80 mm, 110 mm
<b>Rated power</b>	3.7 kW at 1500 rpm
<b>Compression ratio</b>	12.5 – 17.5
<b>Injection pressure</b>	160 bar



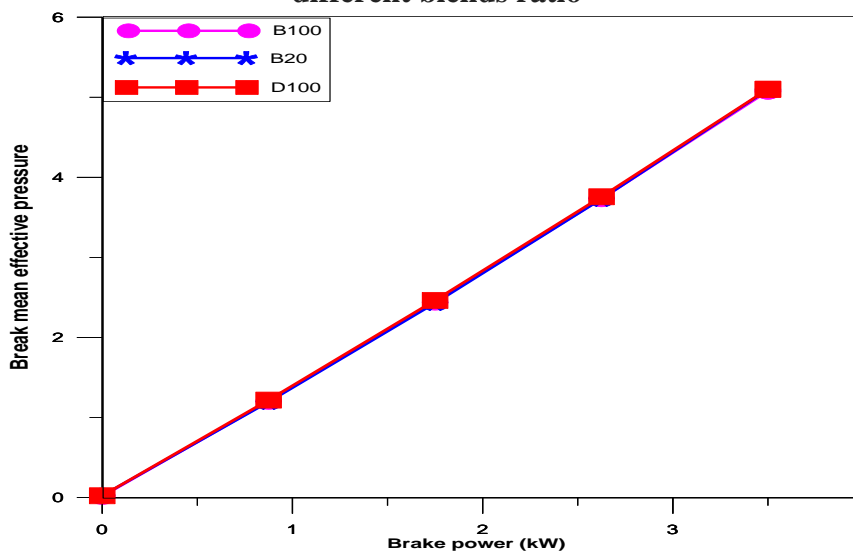
**Fig (3) The variation of cylinder pressure vs. crank angle in full load and no load at different blend ratio**

Fig (4) gives the relation between the brake thermal efficiency and engine brake power. The brake thermal efficiency of diesel fuel is marginally higher than the

efficiency of B20 and biodiesel respectively. Due to the decrease in the caloric value of biodiesel. B20 has decrease in brake efficiency as a compareison with efficiency at net diesel or D100.



**Fig (4) the relation between the brake thermal efficiency and brake power at different blends ratio**



**Fig (5) relation of brake mean effective pressure vs. brake power at different blend ratio**

Fig (5) provides the relation of brake mean effective pressure vs. brake power at different blend ratio. The brake mean effective pressure is generally has same trends and no big difference is observed. The difference in values due to sensible difference in engine brake power at D100, B20, and B100 respectively.

Fig (6) posses the relation of specific fuel consumption vs. brake power at different blend ratio. The specific fuel consumption is decreased with load increment. These trends are reflected in this figure. It is noticed that fuel consumption of diesel less amount than B20 or B100 to produce power. Due to caloric value 1 kg of D100 genrate more brake power than B20 and B100. The curves give a clear view to that diesel engine produce more much energy or power than B20 and B100. Specific fuel consmption for B20 is closed to specific fuel consumption of B100 and both have clear difference than fuel consumption at D100. Again, this is due to the caloric value difference between biodiesel and diesel.

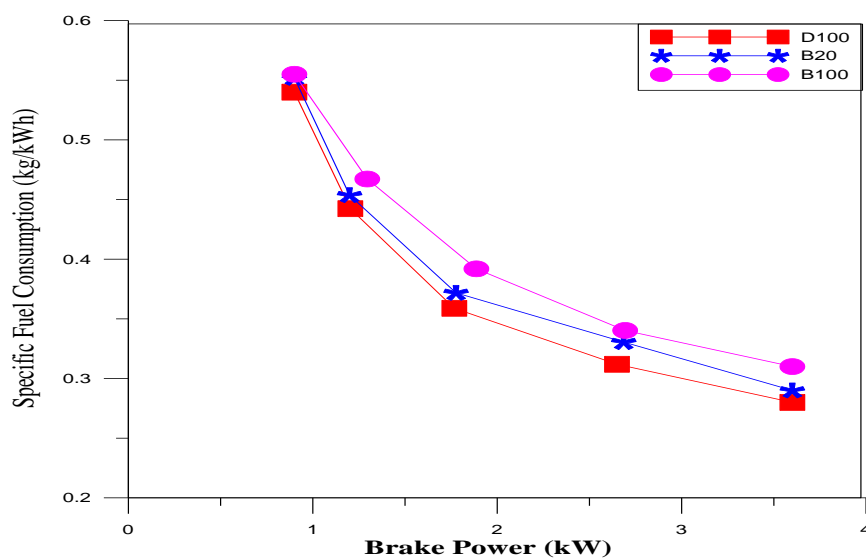
Fig (7) shows the relation between the volumetric efficiency and brake power of engine at different blend ratio. For D100, B20, and B100, volumetric efficiency is slightly decreased with brake power increment. The blends of biodiesel leaves more residual gases in cylinder which is meaning less cylinder volume available to fresh air. Scientific interpretation of this can be explained as at D100 cylinder volume is occupied by less fuel volume. The B20 showed higher value as compared with B100.

Fig (8) provides the relation between the exhaust temperature and brake power at different blends ratio. It is observed that exhaust gas temperatures are increased with engine brake power increasing. Whereas more amount of fuel is burned. Due to caloric value the D100 gives the high exhaust gas temperature. The significant observation is the combustion of B20 blends gave low exhaust temperature as a comparison with D100 and B100. The rate of fuel burned is increasing with load increment to keep speed constant. This released more heat and raised the temperature. There is a margin decreased in exhaust gas temperature of B20 flue gases due to enhancement in combustion.

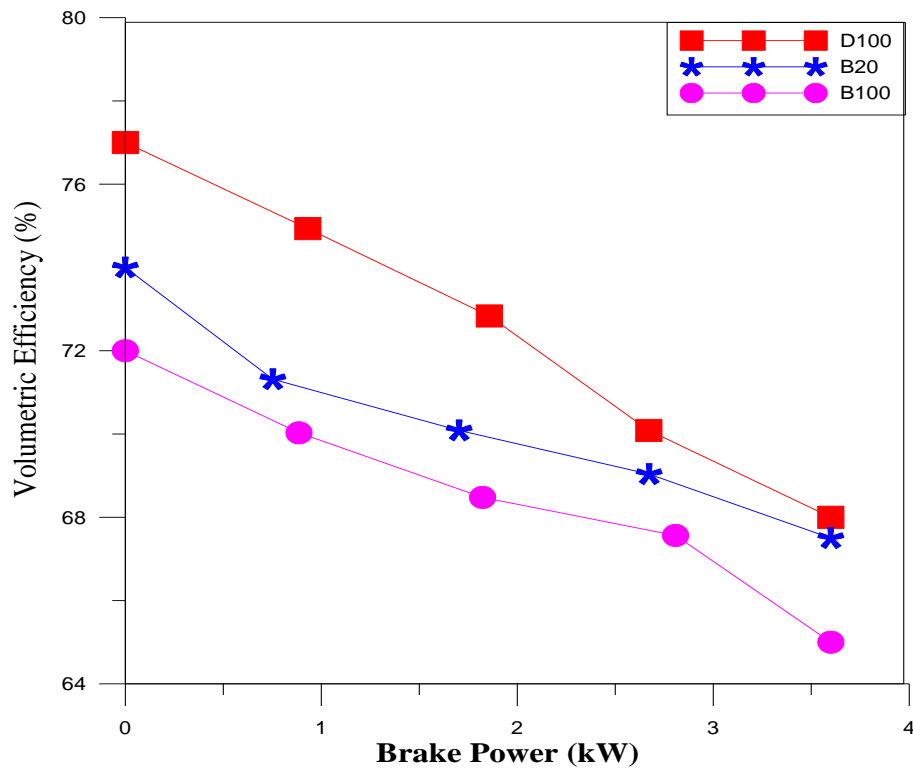
Fig (9) represents the relation between the monoxide and brake power at different blends ratio. It is observed that biodiesel emitted low amount of carbon monoxide. The low carbon content and combustion enhancement due to oxygen existence, the carbon monoxide is reduced almost by 50% at B100.

Fig (10) represents the relation between the dioxide carbon and brake power at different blends ratio. The main indicator of combustion efficiency is the  $\text{CO}_2$  forming. At low load the forming of CO is higher than the forming of  $\text{CO}_2$  as shown in fig (9) and (10). At high load most of burning carbon forms  $\text{CO}_2$ . The blending of biodiesel is reducing the  $\text{CO}_2$  widely. Two reasons stand behind this reduction: first the biodiesel contains less carbon than net diesel D100. Second reason is biodiesel contains oxygen which led to improve the combustion. B20 and B100 reduced the  $\text{CO}_2$  by 19 and 27% respectively.

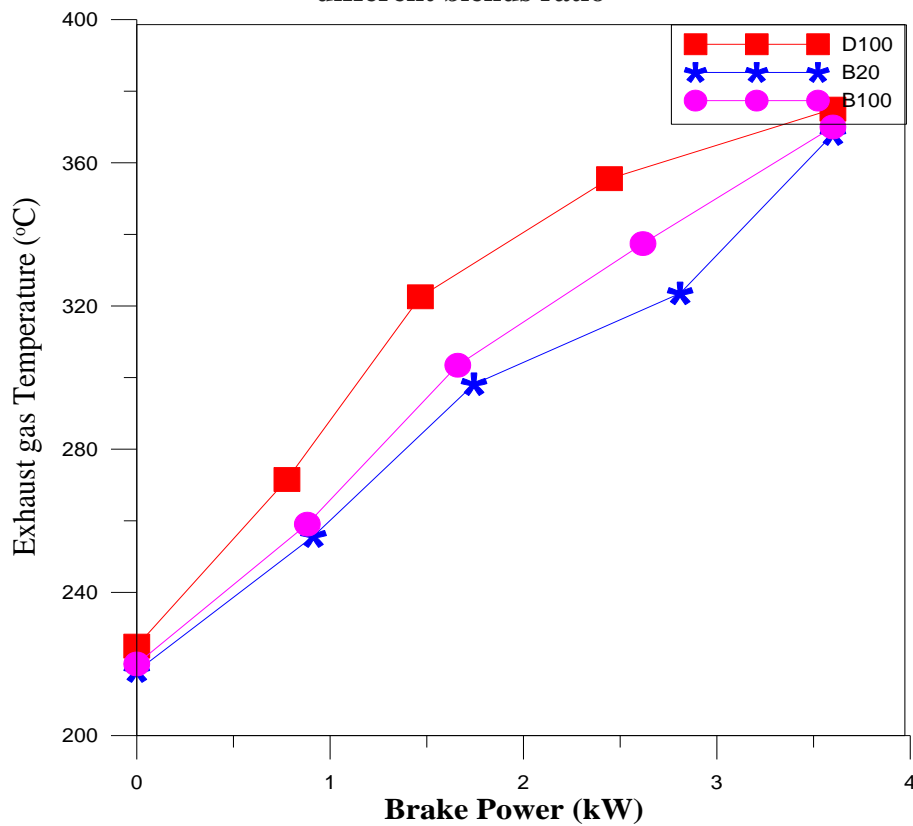
Fig (11) represents the relation between the unburned hydrocarbon HC and brake power at different blends ratio. The blend of biodiesel with diesel decreased the emission of HC. Due to low carbon in chemical structure of biodiesel and oxygen existence, the combustion is run efficiently. The B20 and B100 decreased the HC of diesel fuel emission by 37 and 68 respectively.



**Fig (6) the relation between the brake specific fuel consumption and brake power at different blends ratio**

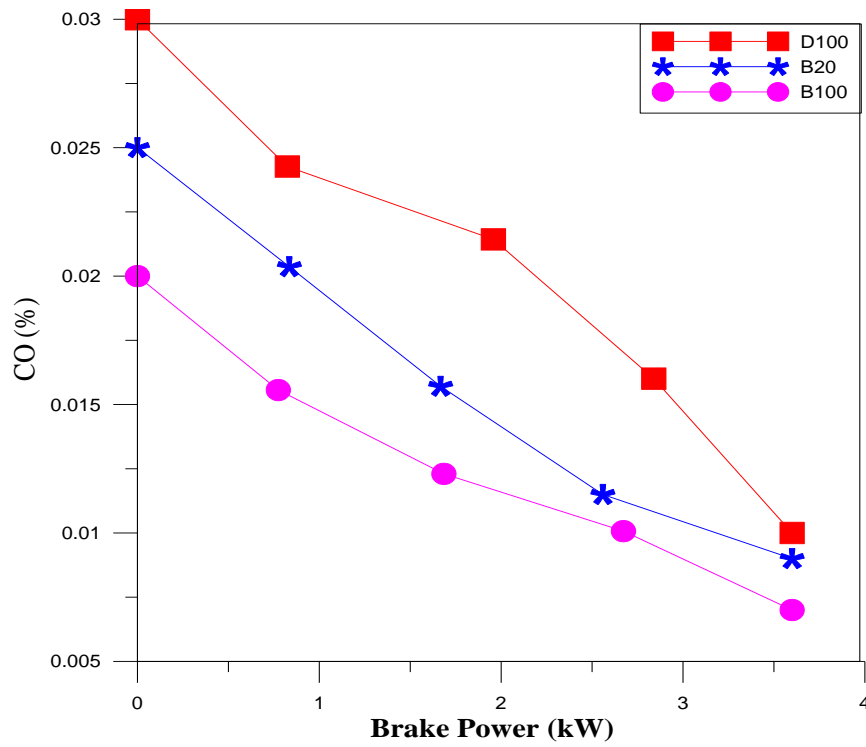


**Fig (7) the relation between the volumetric efficiency and brake power at different blends ratio**

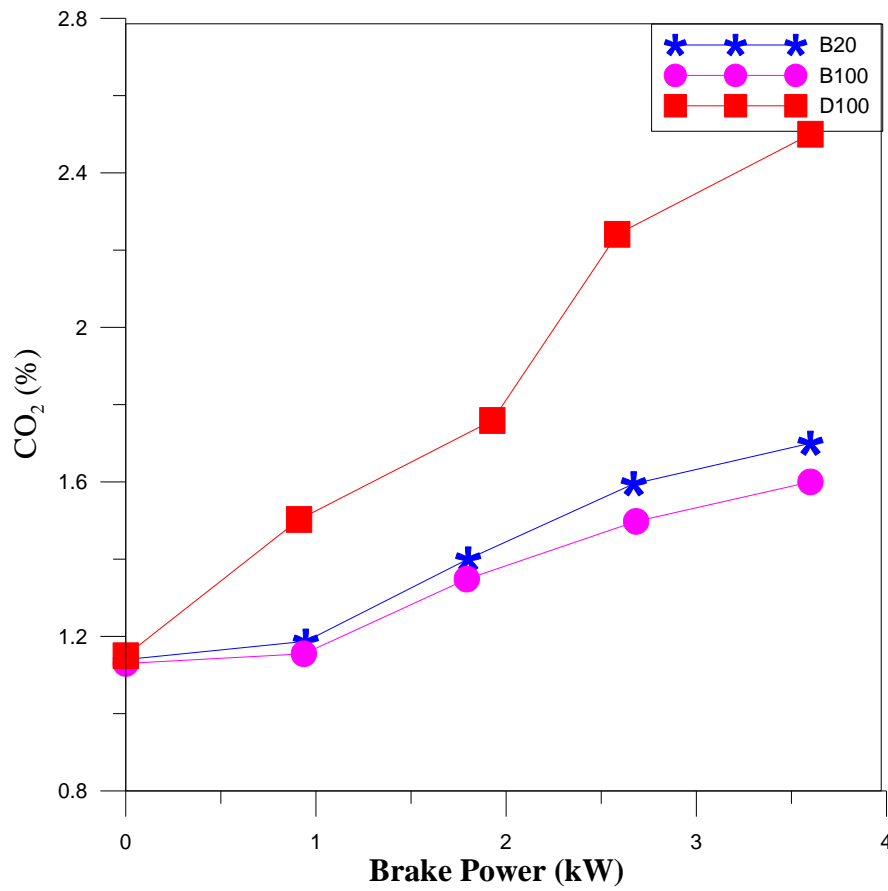


**Fig (8) the relation between the exhaust temperature and brake power at different blends ratio**



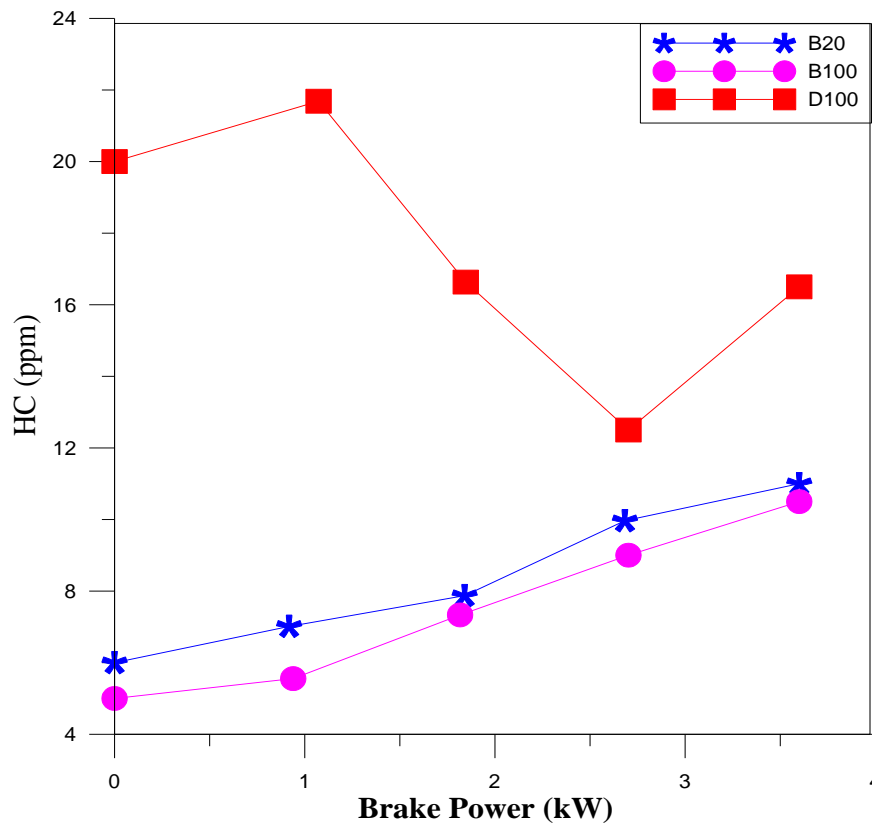


**Fig (9) the relation between the carbon monoxide and brake power at different blends ratio**

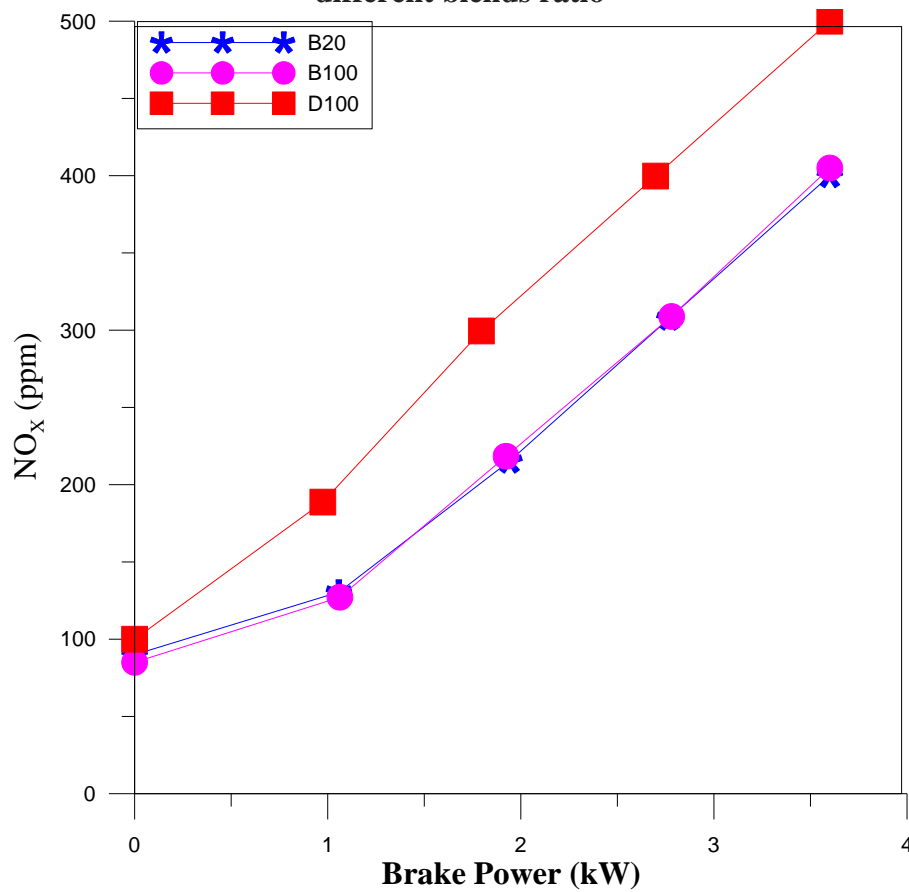


**Fig (10) the relation between the carbon dioxide and brake power at different blends ratio**

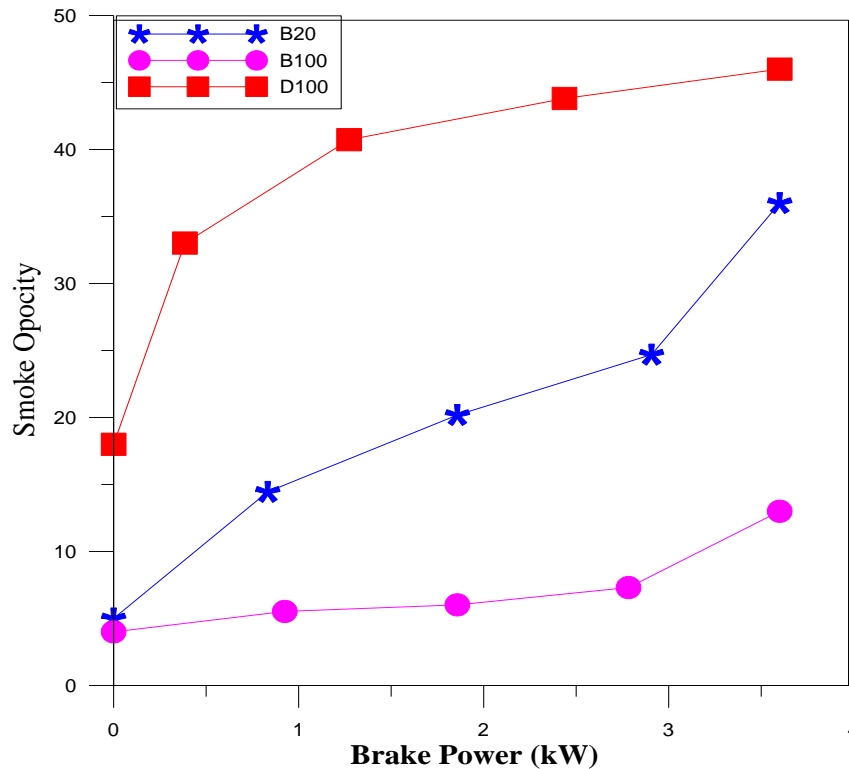




**Fig (11) the relation between unburned hydrocarbon HC and brake power at different blends ratio**



**Fig (12) the relation between NO<sub>x</sub> and brake power at different blends ratio**



**Fig (13) the relation between smoke opacity and brake power at different blends ratio**

Fig (12) gives the relation between the  $\text{NO}_x$  and brake power at different blends ratio. The formation of  $\text{NO}_x$  is a function to excess air in combustion chamber and the temperature inside combustion chamber. With increasing of load, the  $\text{NO}_x$  formation increased due to increase of sucking air. The rate of  $\text{NO}_x$  formation is increased rapidly due to the increase temperature inside combustion chamber. Biodiesel has low Sulphur and aromatic. Biodiesel reduced the  $\text{NO}_x$  due to less sufficient air.

Fig (13) represents the relation between the smoke opacity and brake power at different blends ratio. The smoke is most big trouble in running diesel engines. Smoke is increasing with load increment. At full load, the smoke is decreased 3 times than D100 and nearly 2 times at B20. This is due to high viscosity and complicated molecular structures.

## Conclusion

**In present work, the following points it might be concluded:**

- One of efficient solution to treat pollution is transferring from waste to energy W2E.
- 4 grams of NaOH with 130 ml of alcohol are optimum amounts to synthesize biodiesel from waste cooking oil at 60 °C.
- The economic calculation gives that one liter of biodiesel synthesized in laboratory is cheaper than one liter of diesel.
- Blends of biodiesel with diesel decreases the pollutants.
- B20 (20%biodiesel +80% of diesel) is the best to compromise between thermal efficiency and exhaust emissions.

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