Experimental Comparison Between the Impact of using Two Types of Bio Diesel on Compression Ignition Engine Performance and Emissions

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\textbf{Abstract.} In the nearest future, the biofuel become one of major energy source because of the petroleum fuel scarcity and the high cost of refining the fossil oil. This research is focused on testing two types of biofuel to determine the best fuel for diesel engine operation. Experimental work was conducted for the influence of bio fuels prepared from addition of waste vegetable oils (corn oil and sunflower oil ) in different percent’s to liquid hydrocarbon fuels include diesel in compression ignition engine. The percent adding was varied from 5% to 20% for waste corn oil and waste sunflower oil. The engine speed was varied from 1000 rpm to 2500 rpm to 3000 rpm increment as well as equivalence ratio. It was found that using bio fuel in compression ignition engine lead to reduce CO, UHC, emissions, but increase CO\textsubscript{2} and NO\textsubscript{X} emissions and engine specific fuel consumption. The maximum reduction in CO and, UHC emissions was (25.625%,40.47%), respectively for blend 20% of waste corn oil with 80% diesel. The maximum increase in brake specific fuel consumption was (12.11%,11.4%) for both waste sunflower oil and waste corn oil with gas oil respectively. Also, the maximum increase in CO\textsubscript{2} and NO\textsubscript{X} emission was (41.20%,29.92%) for blend 20% of waste corn oil with 80%diesel, and(36.90%,22.62%), respectively for blend 20% waste sunflower.

\textbf{Keywords:} Waste Corn Oil, Waste Sunflower Oil, Compression Ignition, Alternative Fuels, Combustion.

\textbf{1. Introduction}

One of the appropriate solutions through which the crisis is solved for the increase in the price of fuel and its scarcity in some areas, as well as the reduction of fuel emissions, is the use of biofuels. That type of fuel can be produced by using cheap and expensive methods. Diesel fuel is used in the preparation of biofuels, and sometimes vegetable oils are used. Vegetable oils are used in the kitchens after the expiration of the period of validity where the process here is like a recycling process of waste and prevent the leakage of these oils to sewage, making the process of liquidation difficult and expensive about the methods of water filtration. Starting with the use of biofuels in some countries that have low oil reserves levels using biofuels in all industrial sectors and transport where the process of producing vegetable oils in enormous quantities. Biofuel provides the best solution to reduce the emission rates of pollutants when burned in internal and external combustion engines because it contains the oxygen atoms within the chemical composition of oil and thus makes the proportion of oxygen in the inner room is almost sufficient.

Abuhabaya studied the impact of using biodiesel prepared from vegetable oil and conventional diesel on compression ignition engine performance. The fuel was prepared by mixing conventional diesel and olive oil, into a volumetric percentage of 5%,10%,15%,20% which were tested at later in four-cylinder compression ignition engine has a capacity of 2402 cm\textsuperscript{3}, and compression ratio 17.5:1.

The engine speed in which the biofuel is tested is 1500, 2600, 3300 rpm with the load of
25%, 50%, 75% and 100%. The experimental results explain the emissions of CO, HC, and CO₂ were reduced with increasing the volumetric percentage of sunflower oil in biodiesel as well as the best experimental results depended on methanol volumetric percentage and concentration of sodium hydroxide which work as a catalyst. The output power and torque are reduced by increasing the volumetric percentage of sunflower oil, but the nitrogen oxides were increased due to more oxygen present in biodiesel[1].

Sanli blended mineral diesel fuel (MDF) with waste frying oil (WFO) (in the ratios of 2%, 7%, 15% and 25% for studying the effect of combustion, injection, emission characteristics and performance for (WFO-MDF) blends. The specifications of the engine to test were (Constant engine speed = 2000 rpm and various engine loads (50, 75, 100,125 and 150 Nm). The values of brake specific fuel consumption for MDF were lower than WFO. The waste frying oil (WFO) led to raise in the types measured exhaust emissions and to retreat performance and emission characteristics when the WFO content and engine load increased[2].

Othman has provided in their study a comprehensive review to prepare biodiesel from various waste like waste plastic oil and waste cooking oil. Also, they have studied the influence of the exhaust emissions, engine performance and combustion. They found the election of feedstock is necessary to produce optimum biodiesel. The using of biodiesel in engines has improved performance parameters (output torque and power), and the gases emissions increased CO₂ and NOx and decreased CO and HC emissions when biodiesel was used[3].

Gopal studied the influence of using biodiesel prepared from mixing waste cooking oil with conventional diesel by using transesterification method. The test engine which is used in the experimental work was single cylinder diesel engine air-cooled direct injection four-stroke. The experimental results show that the biodiesles reduced the thermal brake efficiency and the emissions of carbon monoxide and unburned hydrocarbon and smoke opacity. Also, the other effects of using biodiesel in C1 engine was that the biodiesel rises the specific energy consumption [4].

Ilkılıc studied the effect of using biodiesel made by transesterification with short chain methyl alcohols, was produced from sunflower oil, a designated as B100. The test engine specification was four strokes single cylinder direct injection compression ignition engine. The experimental results display that the engine power and torque were decreased but increase the engine fuel when using biodiesel as fuel [5].

Nayak performed an experimental work to investigate the impact of using biofuel prepared from mohau oil and diesel fuel on compression ignition engine performance and emissions. The biodiesel was examined in four-stroke single cylinder water cooled compression ignition engine. The experimental results reveal that the brake power and torque were increased with increasing the percentage of mohau oil in biofuel blend. Also, the specific fuel consumption and emissions of CO, CO₂, UHC, NOx, and smoke were reduced with increasing the concentration of vegetable oil in biodiesel [6].

Atakan studied the effect of using biodiesel as fuel on four strokes four cylinder naturally aspirated compression ignition engine performance and emissions. The volumetric percentage of blending which was used in this study were diesel–biodiesel–butanol (70% diesel–20% biodiesel–10% butanol and 60% diesel–20% biodiesel–20% butanol by volume) and biodiesel–diesel (20% biodiesel–80%diesel and 100% biodiesel by volume). The experimental results reveal that the 20% of butanol blend of biofuel reduced the output torque up to 8.57%. When raised the volumetric percentage up to 20% the output torque and power will reduce up to 12.7% and 13.75 respectively. The specific fuel consumption was increased by of 10.63% and 12.80% with 10% and 20% butanol addition, respectively. In general, the butanol addition process reduced the carbon dioxide and carbon monoxide emissions but increasing the emissions of NOx[7].

Hellier investigated experimentally of the effect of using biodiesel prepared from oil fatty acid composition on diesel engine emission and combustion. The single cylinder modern diesel engine was used in the experimental work. The seven types of vegetable oil were used in experimental work those of corn, groundnut, palm, rapeseed, soybean, sunflower and the micro-algae species. The biodiesel was heated to 60°C before injected in the combustion chamber. The experimental results showed that the delay period increased with increasing the carbon to hydrogen ratio[8].
Gitay compared between the diesel and three types of biodiesel (Canola oil (SVO), Soy biodiesel and waste vegetable oil (WVO) biodiesel) using the engine performance and the emission in a compression ignition engine (6 HP single-cylinder). The experimental results achieved the higher brake specific fuel consumption and lower brake horsepower by using the vegetable oil and the other types of biodiesel [9].

Chaichan prepared three blends of biodiesel from Iraqi produced corn oil after completing the process of transesterification (B100 contains (100% biodiesel), B50 contains (50% biodiesel and 50% diesel), and B20 contains (20% biodiesel and 80% diesel). The researcher used a direct injection diesel engine (4-cylinder) to test the biodiesel blends. The results showed that the concentrations of particulate matter (PM) were reduced significantly when the using of biodiesel compared to diesel at a constant speed and full engine loads were 34.96 %. It is possible to reduce the particulate matter concentrations when minimizing sulfur content for the diesel fuel in Iraq [10].

Radhi in their experimental work for the effect of biofuel on engine performance prepared different blends of biofuel by adding the various amounts of olive and Castrol oils (vegetable oils) into liquid gasoil. They used a compression ignition engine (C.I. engine), the engine type is (Single cylinder, four strokes) for this study. They found the economy of the engine was slightly deteriorated and the environmental pollution was significantly reduced. Also, the results showed the emissions of (CO₂) increased, on the other hand, the emissions of (CO, UHC) decreased [11].

Degife used sunflower oil to produce the biodiesel. It was found in the experiment by increasing catalyst loading; oil conversion will be increased. The maximum preparation of biodiesel was gained when the loading of the catalyst was 20%wt, reaction temperature (150°C), time (5 hours), the ratio of methanol to oil (15:1 molar) [12].

Patil studied the impact of using biodiesel prepared from palm oil and diesel fuel on four strokes four-cylinder direct injection diesel engine. The experimental results show that the increasing in volumetric percentage of palm oil causes an increase in emissions of carbon monoxide, nitrogen oxide and unburned hydrocarbon. The thermal efficiency was decreased, but the brake specific energy consumption is increased due to increasing the fuel viscosity by increasing the percentage of palm oil in the fuel. So, from the results, it can be concluded that 10% blend is considered as the best compare to other blends at 95% load condition [13].

This study was focused on the comparison on two types of fuel one prepared from mixing the Iraqi diesel fuel with waste sunflower oil and the other prepared from waste corn oil to select the best fuel for produced into the huge amount for use as a biofuel in internal combustion engines. The method by which this biofuel was prepared is an economical method where it can investigate saving the money. The expired oils may cause a problem in equipment water recycling plant which causes clogging in the tubes and passages of the water treatment plant so that its needed to continuous maintenance which will raise the operation cost of the plant. The two types of biofuel which are prepared from expired vegetable oils and concerned with the impact of using biodiesel prepared from conventional Iraqi diesel fuel and waste sunflower oil. In this research, the engine speed was varied from 1000 to 2500 to 300 rpm increments. The emissions were measured by using the gas analyser. There are two benefits from this experimental study as below:

1 Reduce the engine emissions because of the prepared biofuel contained oxygen atoms with its chemical composition.
2 Decrease the fuel cost because of the biofuel prepared from waste oil.
3-Knowing the best fuel type for using it in internal combustion engines.

2. Engine Performance mathematical model

Based on general heat engine thermodynamics, the engine performance can be simulated according to the following simple model:

\[ \dot{m}_f = \frac{v_F}{\text{time}} \times \rho_F \text{ kg/sec} \]

(1)
2- brake power
\[ bp = \frac{2\pi N \tau_b}{60 \times 1000} \text{ kW} \] ............................................ (2)

3- Brake specific fuel consumption
\[ \text{bsfc} = \frac{m_f \times 3600}{bp} \text{ kg kW/hr} \] ............................................ (3)

4- Air consumption (C.I. engine)
\[ \dot{m}_{\text{act}} = 2.056 \times 10^{-4} \times \sqrt{\nabla P} \text{ kg sec}^{-1} \] ................. (4)

5- brake thermal efficiency
\[ \eta_{\text{bth}} = \frac{bp}{m_f \times \text{LCV}} \] ............................................ (5)

Where;
\( V_f \): the volume of fuel consumption.
\( \rho_f \): the density of fuel kg/m\(^3\).
\( N \): rotational speed rpm.
\( Tb \): Torque of engine N.m.
\( \nabla P \): pressure differences by the manometer.
\( \text{LCV} \): low heating value J/kg

3. Experimental work
The experimental work of this research is completed in internal combustion engines laboratory in Kerbala university. The test rig in which the experimental work is accomplished, it was designed and manufactured in arm filed company, the test rig provided with good instrumentation tools in which can be measured the important engines parameters during the calibration process of the engine under the influence of different factors.

3.1. Experimental setup
The trial rig includes four strokes; single cylinder diesel engine has a capacity of, 175 cm\(^3\), cooled by air, coupled with swing dynamometer via a belt to measure the brake torque and power as shown in figure 1. On the other hand technical specification is shown in Table (A.1).

The dynamometer worked as a starter at first of engine operation and loaded the engine throughout of the engine operation. The dynamometer speed is regulated by using new control system. The engine parameter calculated in this test rig is brake torque (N.M), engine speed (r.p.m), exhaust temperature, engine emissions, air consumption and fuel consumption. The brake torque is measured by using torque sensor which is installed beside the dynamometer. The torque sensor which is shown in figure 2 is loaded due to the large difference in speed between the dynamometer and engine to permit the dynamometer swing and exerted a load on torque sensor which produces the electric signal due to this load. The engine speed is measured by using speed sensor which is installed at the end of the dynamometer shaft. The consumption of fuel is evaluated by using a scalar cylinder and stopwatch. The air consumption can be measured by using airbox which is connected to the engine intake manifold by using rubber pipe. The exhaust temperature is measured by using a thermocouple which is installed before the exhaust muffler.

Exhaust gas analyzer type (mod 488 – Italy) was used to measure the engine emissions. The analyzer evaluates the percentage of the carbon monoxide, carbon dioxide, unburned hydrocarbon, and nitrogen oxide in the exhaust gases.
3.2. BioFuel heating value Measurements

The biofuel which prepared by blending the two types of waste cooking oil into suitable volumetric percentage causes a noticeable change in diesel properties. The calorific value of the fuel is one of property which is changed due to the mixing process. The heating value was measured via using bomb calorie meter as shown in figure 3. The heating value in both types of biodiesel was reduced with the increasing in volumetric percentage of waste vegetable oil. The results of the experimental test which are shown in figure 4 explain that the biofuel heating value is lower than the conventional diesel fuel heating value due to oxygen presence in biofuel. The excess oxygen will not participate in combustion process but absorbs the heat from the flame in all stages of combustion so that the adiabatic flame temperature will reduce which will cause a reduction in heating value of biofuel.
3.3. Experimental procedure
The experimental work is accomplished in the following procedure.
I. The interventions tools are calibrated to ensure its measure the engine parameter inaccurate values. The biofuel was prepared earlier before starting the test.
II. Measuring engine speed, brake torque, the pressure differential between the atmosphere and pressure inside the airbox, engine emissions (CO, HC, NO, CO\(_2\)) and timing of fuel consumed for the volume of (100) ml with and without using the two types of biofuel.

4. Results and Discussion
The results of engine calibration which are collected from practical work when fueled the engine with the different types of bio fuel prepared from waste sun flower oil and conventional Iraqi diesel fuel include measuring of brake power, fuel consumption, brake specific fuel consumption and engine emissions.

The results of the practical work are abstracted and discussed as a below:
1- The increasing in volumetric percentage of blending corn oil and sun flower oil into the value of (95%,90%,85%,80%) diesel fuel with (5%,10%,15%,20%) corn oil respectively, results in an increase in the fuel consumption. The maximum increasing of fuel consumption in corn oil and diesel mixture is (11.4%) at 20% volumetric percentage of corn oil and 80% of diesel, but for sun flower oil and diesel blend is (12.11%) for the same percent of the blend as shown in figure 5. The increasing in fuel consumption occurs due to oxygen presence in fuel chemical composition in huge amount absorbed the heat from the nuclear of flame during developing a process so that the high pressure which is generated due to combustion process during power stroke reduce therefore the output power will be reduced.

2- The increasing in volumetric percentage of vegetable oil in biofuel lead to rising the specific fuel consumption. The maximum increasing of the specific fuel consumption when using corn oil and gasoil blend is (11.4%) at 20% volumetric percentage of corn oil and 80% of the gas oil. However, for sun flower oil and gasoil blend are (12.11%) for the same percentage of the blend as shown in figure 6. The increasing in specific fuel consumption occurs due to oxygen presence within combustible elements which play an essential role in energy mitigation and reduction in combustion temperature.

3- The carbon monoxide emission decreased with increasing the amount of waste cooking oil (corn oil and sun flower oil) in conventional diesel as shown in figure 7. The maximum lowering in CO emission when using diesel and waste corn oil blend is, (25.625%) but when using waste sun flower oil and diesel blend is (24.375%). This maximum reduction occurs when
using a blend containing 20% of corn oil or sunflower oil and 80% conventional diesel. The reason for CO reduction is due to oxygen presence in excess amount causes carbon monoxide atoms to complete oxidation approximately. Also, the oxygen presence causes a reduction in combustion temperature in this situation the dissociation CO₂ to CO will be reduced.

4-The unburned hydrocarbon (UHC) emission decreased with increasing volumetric percentage of waste corn oil and waste sunflower oil in the conventional diesel. The maximum lowering in (UHC) emission when using diesel and corn oil blend is (40.47%), but when using waste sunflower oil and diesel blend is (35.71%). This maximum reduction occurs when using a blend containing 20% of waste corn oil or waste sunflower and 80% conventional diesel. Figure 8 shows the decreasing in (UHC) emission with increasing the volumetric percentage of waste vegetable oil in the conventional diesel. The main reason of this slight decreasing is that the existence of oxygen molecules within in fuel atoms causes increasing in quantity of oxygen within the combustion chamber in this situation the fourth stages of combustion process for diesel fuel will accelerate rapidly due to more oxidizer presence.

![Figure 5](image1.png)

**Figure 5.** Displays the relation between engine speed and fuel consumption (L/h) engine in C.I. engine for both types of the blend.

![Figure 6](image2.png)

**Figure 6.** Shows the relation between engine speed and b.s.f.c. in C.I. engine for both types of biofuel.
Figure 7. Shows the relation between engine speed and (CO) emission in compression ignition engine for both types of biofuel.

Figure 8. Shows the relation between engine speed and (UHC) emission in compression ignition engine for both types of biofuel.

Figure 9. Shows the relation between engine speed and NOx emission in compression ignition engine with and without using biofuel.
5-The nitrogen oxide (NOx) emission is increasing with increasing volumetric percentage of waste corn oil and waste sunflower oil in the conventional diesel. The maximum increasing in (NOx) emission when using diesel and waste corn oil blend is (29.92%), but when using waste sunflower oil and diesel blend is (22.62%). This maximum increasing occur when using a blend containing 20% of corn oil or sunflower oil and 80% conventional diesel. Figure 9 shows the increase in (NOx) emission with increasing the volumetric percentage of vegetable oil in the conventional diesel. The biofuel chemical composition contained oxygen which plays an essential role in nitrogen oxides formation throughout of combustion process so that the nitrogen oxides emissions will increase when using this type of biofuel.

6–The carbon dioxide (CO2) emission increased with increasing volumetric percentage of waste corn oil and waste sunflower oil in conventional. The maximum increasing in (CO2) emission when using diesel and corn oil blend is (41.20%), but when using sunflower oil and diesel blend is (36. 90%). The maximum increase in emissions occurs when using a blend containing 20% of sun flower oil or corn oil and 80% conventional diesel. Figure 10 shows the increase in (CO2) emission with increasing the volumetric percentage of vegetable oil in conventional gasoil. This behavior of increasing in (CO2) emissions attributed to that the oxygen existing in biofuel produce complete combustion and create more carbon dioxide. Moreover, the high carbon dioxide emissions for the mixtures was attributed to the presence of carbon monoxide in the fuels, with part of the CO produced was converted into CO2[14]. In general, the biofuel is prepared from waste corn oil and diesel to give a lower level than the biofuel prepared from waste sunflower oil in of fuel consumption. Morever the first blend gives a lower specific fuel consumption, carbon monoxide emissions and unburned hydrocarbon emissions this behavior attributed to that the blend of waste corn oil and diesel has low density, viscosity, carbon to hydrogen ratio and flash point temperature than the blend of waste sunflower and diesel blend. The blend of waste sunflower oil has lower emissions of carbon dioxide and nitrogen oxide than the blend of waste corn oil and diesel this due to that the blends of sunflower oil have a low heating value, combustion temperature, and oxygen content than waste corn oil and diesel.
Table A-1. Main technical specifications of compression ignition engine.

| Compression ignition engine                     |                  |
|------------------------------------------------|------------------|
| Engine type                                    | Single cylinder, four stroke |
| Engine model                                   | 95310            |
| Ignition timing                                | 25° BTDC         |
| Displacement                                   | 118cm³           |
| Valve per cylinder                             | two              |
| Bore                                           | 60 mm            |
| Stroke                                         | 42 mm            |
| Compression ratio                              | 17               |
| Engine cooling type                            | forced air cooled|
| Lubrication                                    | Forced lubrication|
| Engine oil capacity                            | 1.5 L            |
| engine rotation direction                      | counterclockwise (view from output shaft) |

5. Conclusions
The comparison between the impact of using two types of biodiesel prepared from waste sunflower oil and corn oil on compression ignition engine performance and emissions can be concluded as below.

1-Both types of biodiesel reduced the emissions of CO and HC, the reduction in emissions when using corn oil and diesel blend is higher than the reduction in emissions when used sunflower and diesel blend. This behavior of reduction in these pollutants attributed to that the biodiesel has oxygen atoms in its chemical structure enhance the combustion process and give complete combustion.

2-The emissions of CO₂ and NOₓ are increased when biodiesel engine emissions due to increasing the combustion efficiency.

3-Both types of biodiesel cause reduction in fuel consumption and specific fuel consumption because of the oxygen presence lowering the heating value. The reduction in fuel consumption and specific fuel consumption when using the blend of corn oil and diesel fuel is lower than when using sunflower oil and diesel blend because of the heating value of waste sunflower oil, and diesel blend is lower than the heating value of waste corn oil and diesel blend.

6. References
[1] A Abuhabaya, J Fieldhouse and D Brown 2013 “The optimization of biodiesel production by using response surface methodology and its effect on compression ignition engine,” Fuel Process. Technol., vol. 113, pp. 57–62.
[2] Sanli and Huseyin 2018 "An experimental investigation on the usage of waste frying oil-diesel fuel blends with low viscosity in a Common Rail DI-diesel engine." Fuel 222,pp. 434-443
[3] Othman Mohd Fahmi, et al 2017 “Green fuel as alternative fuel for diesel engine: A review.” Renewable and Sustainable Energy Reviews 80, pp.694-709
[4] K N Gopal, A Pal, S Sharma, C Samanchi, K Sathyanarayanan and T Elango 2014 “Investigation of emissions and combustion characteristics of a CI engine fueled with waste cooking oil methyl ester and diesel blends,” Alexandria Eng. J., vol. 53, no. 2, pp. 281–287
[5] Ilkilic, Cumali, and Cengiz Oner 2017 "Biodiesel Fuel Obtained From Sunflower Oil As An Alternative Fuel For Diesel Engines." The Online Journal of Science and Technology-July 7.3
[6] S K Nayak and B P Pattanaik 2014 “Experimental investigation on performance and emission characteristics of a diesel engine fuelled with mahua biodiesel using an additive,” Energy Procedia, vol. 54, pp. 569–579
[7] Akar and Mustafa Atakan 2016 "Performance and emission characteristics of compression ignition engine operating with false flax biodiesel and butanol blends." Advances in Mechanical Engineering 8.2
[8] P Hellier, N Ladommatos and T Yusaf 2015 “The influence of straight vegetable oil fatty acid composition on compression ignition combustion and emissions,” Fuel, vol. 143, pp. 131–143
[9] Gitay Js and Gr Selokar 2017 "Critical Analysis & Performance Evaluation Of Ci Diesel Engine Using Bio Diesel."
[10] M T Chaichan 2016 “Evaluation of emitted particulate matters emissions in multi-cylinder diesel engine fuelled with biodiesel,” *Am. J. Mech. Eng.*, vol. 4, no. 1, pp. 1–6

[11] R M Radhi and M S Imran 2016 “Effect of Using Dual Fuel on Compression ignition engine performance,” vol. 12, no. 4, pp. 37–47

[12] W Degife, M Ashenafi, R Thiagarajan and O Sahu 2015 “Extracted Biodiesel as Feed for Internal Combustion Engine,” vol. 3, no. 1, pp. 1–7

[13] Patil, Ravindra A, Tushar A Koli and V H Patil 2016 "Performance, Emissions And Combustion Evaluation Of Ci Engine Using Biofuel," mechanical department, gf’s gcoe north maharashtra university jalgaon., jalgaon, india, an international journal of science, engineering and technology research (ijsetr), volume 5, issue 1

[14] H Shih and J Hsu 2012 “A Computational Study of Flammability Limits of Opposed-Jet Syngas Diffusion Flames,” *Int. J. Hydrogen Energy*, vol. 36, no. November, pp. 15868–15879