The effect of first generation biofuel on emission characteristics under variable conditions of engine speeds and loads in diesel engine

Mohammed A. Fayad*1, Miqdam T. Chaichan2, Hayder A. Dhahad3

1, 2 Energy and Renewable Energies Technology Center, University of Technology-Iraq, Baghdad, 3 Mechanical Engineering Department, University of Technology-Iraq, Baghdad, Iraq

Mohammed.A.Fayad@uotechnology.edu.iq
miqdam.t.chaichan@uotechnology.edu.iq
hayder.a.dhahad@uotechnology.edu.iq

Abstract: Iraqi sunflower was used in the current study and blended with diesel fuel into different ratios. The results indicated that lowest level of gaseous emissions (CO, HC, and CO2) and PM produced from B100 compared with other fuels tests. Furthermore, the CO and unburnt HC decreased with high conditions of engine loads and speeds. The high concentration of NOx emissions was found from the combustion of B100, B50, and B20 compared with diesel fuel. The emissions of NOx and exhaust gas temperature improved from increasing the operating conditions of engine loads and speeds. The effect of biodiesel blends on the gaseous emissions and particulate matter (PM) was investigated under variable engine operating conditions of loads and speeds. The best reduction was achieved with medium conditions of engine loads and speeds compared with low and high loads and speeds for all fuels tests. The higher oxidation rate of soot particles inside combustion cycle from the burning of B100, B50, and B20 decreased the total concentration of PM.

Keywords: Biodiesel, diesel engine, load, speed, NOx, particulate matter (PM).

1. Introduction

The fluctuation of crude oil prices, up and down, has caused the eager search for alternatives to conventional diesel fuel from renewable energy resources. Oil and its derivatives have harmful effects on public health and the environment, as their burning emits toxic emissions that cause greenhouse gases and global warming [1-2]. One of the characteristics of any fuel that is an alternative to fossil fuels is able to avoid the problems of the fossil fuels by reducing the levels of harmful emissions and particulate matter (PM). The researchers suggested several solutions, such as using the water-diesel suspension [3], adding nanoparticles to the diesel [4, 5], or adding biodiesel [6, 7]. Biodiesel is a renewable and environmentally friendly fuel. It is also characterized by the cetane number, which is relatively close to the cetane number of diesel, and does not contain aromatic substances or sulfur. Furthermore, it is characterized by the
presence of approximately 10% (or more, depending on the source of its production) of oxygen in its chemical composition compared to diesel [8, 9]. The pollutants emissions produced from biodiesel combustion in compression ignition engines such as hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) are low in comparison with diesel. However, nitrogen oxides concentrations are higher in the exhaust gas [10, 11]. Therefore, blending of biodiesel with diesel fuels in different weight and volume ratios was used. Previous study suggested using biodiesel blends instead of pure biodiesel to reduce its disadvantages to engine performance [12]. Several studies have shown that the use of pure biodiesel reduces emissions of PM and nitrogen oxides, as well as the concentrations of HC and CO [13, 14]. At the same time, many researchers have shown that nitrogen oxides concentrations increase when pure biodiesel is used in diesel engine [15–18].

A large number of types of biodiesel extracted from various types of crops have been studied and tested, in addition to different types of waste cooking oils [19]. Fayad et al. [20] studied the effect of mixing biodiesel extracted from Jatropha in ratios (JB0, JB20, JB50 and JB100) with diesel on the performance and pollutants of a three-cylinder CI engine. They found that using 20% of this biodiesel improved brake power from 0.09 to 2.64% while when adding biodiesel by 50% the improvement was from 0.05 to 3.8% compared to diesel. It is reported that using biodiesel blends reduces hydrocarbon (HC) and particulate (PM) emissions. El-Kasaby and Nemit-allah [21] concluded that adding 10% of the biodiesel extracted from Jatropha (JB10) provides the highest thermal brake efficiency compared to the biodiesel-diesel blends (JB0, JB20, JB30 and JB50). Mixtures with higher biodiesel concentrations such as JB30 and JB50 have significantly reduced carbon dioxide concentrations. Islam et al. [22] verified the effect of biodiesel extracted from Cryptothecodium cohnii dinoflagellates when mixed with waste cooking oil and added fossil diesel. Algae oil was added in proportions (10%, 20% and 50%) to 20% of the waste cooking oil methyl ester and diesel. The results of the study showed that there was a clear rise in the levels of nitrogen oxides at full load. As for the hydrocarbon concentrations emitted, they were similar to what was emitted from the diesel engine. Arbab et al. [23] analysed emissions emitted from a variable speed and full loaded diesel engine with a mixture of coconut and palm oils extracted biodiesel (20%) with diesel. The lowest BSFC and highest brake power from the combination blend of 80% diesel and 20% biodiesel than to the diesel with a turbocharger. Also, the emission concentrations when using this mixture (PC20) were lower compared with a pure fuel. The mixing of the two bio-liquids resulted in a new type of biodiesel with better properties compared when using them alone as an additive to diesel. The concentrations of CO, CO₂, unburned hydrocarbons, nitrogen oxide and smoke were significantly lower in case of biodiesel blends compared to the diesel fuel.

Fayad et al. [24] suggested that using yellow grease from Waste Cooking Oil in Restaurants (WCO) as a clean and renewable fuel by blending it with n-pentanol and fossil diesel in different ratios. The researchers studied three triple mixtures (D50-WCO30-, D50-WCO40-P10, P20D50-WCO45-P2and) intending to replace fossil diesel with at least 50% (45% WCO, 20% n-pentanol) by volume. The studied mixtures showed a decrease in viscosity by up to 45%, and the cetane number was similar to that of diesel. Smoke opacity decreased, HC emissions increased while carbon dioxide levels remained unchanged when the engine was operating with the above mixtures. The concentrations of nitrogen oxides increased with the increase of n-pentanol in the mixture, however these concentrations were lower than what was emitted from diesel for all engine operating conditions. Fattah et al. [25] examined biodiesel in diesel engine from Calophyllum inophyllum Linn oil (CIBD) using sulfuric acid (H₂SO₄) with potassium hydroxide (KOH) as catalyst. Antioxidants have also been added to the biofuel to increase its stability. When testing the fuel in a diesel engine, the findings revealed an increase in nitrogen oxides and a decrease in levels of carbon dioxide and hydrocarbons. The use of antioxidants reduced nitrogen oxide levels by 1.6 to 3.6%. However, this addition caused an increase in the levels of carbon dioxide and hydrocarbons, but it remained lower than the concentrations emitted from engine. The researchers found that the combination of CIB20 and antioxidants could be used in CI engines and don’t need further modifications in engine. These results are consist with numerous studies [26, 27] findings. This work
targets to evaluate the possibility of using local produced oil in producing biodiesel which can be a good alternative to diesel. The tests were conducted to produce biodiesel from Iraqi origin sun flower oil employing chemical process with methanol and Sodium hydroxide as a catalyst. The success in using such green environment friendly fuel in diesel engine will spare Iraqi environment from the damages caused by high sulfur content diesel fuel used nowadays. Furthermore, the aim of this study is to investigate the effect of Iraqi sun flower oil on gaseous emissions and particulate matter under several of engine operating conditions.

2. Experimental setup

The four cylinders, direct injection, natural aspirated diesel engine (Fiat engine) was used in this study. The research engine specifications are listed in Table 1 [28]. Simple schematic diagram of the used engine and its accessories is presented in Figure 1(a). The emissions emitted from diesel engine such as CO, HC, CO$_2$, and NOX were measured using Multigas mode 4880 emissions analyzer. A hydraulic dynamometer coupled with diesel engine to control the engine loads. The parameters of engine performance were calculated using the equation in the previous works [29, 30]. The PM concentrations emitted from engine were measured using Whatmann-glass micro-filters and air sampler with low volume (type Sniffer L-30). The filter weight was measured and recorded before and after test. The plastic bags temporarily were used to preserve the filters samples at the end of the test to analyzed and weighted. PM concentrations were determined using the following equation [31]:

$$PM \text{ in (µg/m}^3\text{)} = \frac{w_2 - w_1}{V_t} \times 10^6$$  \hspace{1cm} (1)

Where: PM is the concentration of particulate matters (µg/m$^3$), $w_1$ is weight of filter sample before taken specimen in (g), $w_2$ is the weight of filter sample after taken in (g).

To calculate $V_t$ using equation below:

$$V_t = Q_t \cdot t$$  \hspace{1cm} (2)

Where: $Q_t$ is the air flow rate (elementary and final) through the device (m$^3$/sec), and $t$ represented the time of sampling in (min).
Table 1. 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= 1600         |
|                           | Nozzle opening pressure = 40 Mpa |

Figure 1(a). Schematic diagram of the engine and experimental setup.

The engine used and tools that connected with research engine are illustrated in Figure 1(b) in this study. Several thermocouples located on intertwined double-tubes wall of the heat exchanger to measure the temperature of the working liquids. During this study, Variable sets of the test were conducted for different blends of biodiesel to study the inhibition or promotion of gaseous emissions and PM to evaluate theses emissions for equivalence ratio and engine condition (load and speed).
Figure 1(b). Real picture of the engine and tools setup.

2.1 Fuels preparation

The biodiesel blends used in this study were B20 (20% biodiesel and 80% diesel), B50 (50% of biodiesel and 50% of diesel), and B100 (100% neat biodiesel). The engine PM emissions and engine performance were measured for three biodiesel blends and compared with diesel fuel under variable of engine operation conditions. The blends properties of B100, B50, B20 and diesel fuels are presented in Table 2. These properties are measured by different equipment at laboratories of Chemical Engineering Department, University of Technology-Iraq. The ratio of 5.87 and 11.1 represent the oxygen content in the blends of biodiesel that obtained during measurement and this is agree with previous studies [32, 33].

Table 2. Specifications of tested fuels.

| Fuel type | Calorific value (kJ/kg) | Density (g/dm³) | Viscosity (mm²/s at 27 °C) | Cetane No. | Flame point (°C) | Cloud point (°C) | Pour point (°C) |
|-----------|-------------------------|-----------------|----------------------------|------------|-----------------|-----------------|----------------|
| Diesel    | 44227                   | 810             | 4.23                       | 49         | -13.8           | -3.7            | -29            |
| B100      | 39873                   | 906             | 65                         | 38.6       | 239             | -7.7            | -12.4          |
| B50       | 40368                   | 877             | 44.7                       | 40.6       | 179             | -10.2           | -17.833        |
| B20       | 41654                   | 829             | 14.38                      | 42.9       | 112             | -11.78          | -24.68         |

2.2 Test procedure

Three fuel blends (B20, B50 & B100) were examined in this study to operating the diesel engine under various engine loads and speeds. The engine emissions and particulate emissions were measured and analyzed under variable of operating condition of engine loads and speeds. The variation results of engine performance and PM emission from biodiesel blends were compared with results obtained from the base fuel of diesel to define and determine the beneficial effect of renewable fuel combustion from different fuel blends.
3. Results and discussion

The effects of variable engine loads and different blends of biodiesel (B20, B50, and B100) on CO emissions are shown in Figure 2 under 1500 rpm of engine speed. The level concentration of CO emission decreased from the combustion of B20, B50, and B100 compared with diesel under high engine load. It can be seen that the best reduction in the CO emission with lower load condition. The gas temperatures into the combustion cycle increased at higher engine load [34]. Furthermore, the enhanced air-fuel mixing and improve the atomized fuel particles evaporation leads to produce lower CO concentration through a high rate of CO to CO$_2$ conversion. The high oxygen content (by 9.94 wt. %) in the biodiesel result in more completes combustion and lower exhausts emissions.

![Figure 2](image-url)

**Figure 2.** Effects of different renewable fuels and engine loads on CO concentrations under constant engine speed.

Figure 3 shows the level of hydrocarbon (HC) emission concentration emitted from biodiesel blends under variable engine loads. The trend of incomplete combustion can be determined from the unburnt HC emission [35]. The HC emission diminished through increasing the ratio of fuel blends from biodiesel. The concentration of HC emission ranged from 82 ppm with low load and 37 ppm with full load from diesel fuel, while it ranged from 28 ppm with low load and 11.6 ppm with full load from B100. In addition, HC emission ranged from 65 ppm and 31 ppm from both operating condition low load and full load, respectively. The increasing engine torque produced higher HC concentration due to the cooler combustion chamber. It is reported that the HC remained in the crevice volume unburned and along the cylinder wall [1].
Figure 3. Effects of different renewable fuels and engine loads on HC concentrations under constant engine speed.

The variation in the NOx emissions under variable engine loads is shown in Figure 4 for B100, B50, and B20. The values of NOx emissions increased from blends of biodiesel (B20, B50, and B100). The combined effect of in-cylinder temperature and oxygen availability are responsible of increase the concentration of NOx emissions [36]. Higher oxygen-born in the molecule structure of biodiesel blends by 11% compared to the diesel fuel enhances the NOx formation in the combustion cycle. The high engine load enhances the combustion temperature which results in boost the NOx formation for all fuel tests.

Figure 4. Effects of different renewable fuels and engine loads on NOx concentrations under constant engine speed.
The values of CO₂ emissions produced from the burning of B20, B50, B100 increased under variable engine loads are shown in Figure 5. The increased in CO₂ emissions indicated that the burning of biodiesel blends tappers to improve combustion compared with diesel fuel under variable engine load conditions. Also, the carbon molecules were noticed to be decreased and the oxygen molecules increased during the biodiesel combustion.

![Figure 5. Effects of different renewable fuels and engine loads on CO₂ concentrations under constant engine speed.](image)

The PM concentration in the exhaust from combustion of biodiesel blends is shown in Figure 6 under variable conditions of loads. Soot particles in the PM composition produced when the fuel has zero oxygen to interact with these soot particles. Moreover, PM generated during the combustion process inside the fuel rich zone of the combustion cycle [31, 35]. Different blends of biodiesel decreased the PM concentration in the exhaust pipe, especially under low engine load. Furthermore, PM concentration significantly reduced with medium and high engine load from biodiesel blends combustion compared with diesel. According to the Figure 6, it was achieved that 34.96% represent the maximum reduction from B100 combustion compared to the diesel under high load.
Figure 6. Effects of different renewable fuels and engine loads on PM concentrations under constant engine speed.

Figure 7 shows the effects of engine speeds and biodiesel blends on CO concentration for fixed engine load. The reduction in CO concentration starts with the engine speeds increasing for all fuels tests. Besides, the lower level of CO emission decreased under low engine speed. It can be observed that the surrounding air and mixing of the atomized fuel enhanced at higher engine speeds which leads to increase the burning gas temperature in the combustion cycle [1, 25]. According to that, the conversion rate of CO to CO₂ emissions increased. The results from this study indicated that the lower CO emission and more complete combustion from the combustion of neat biodiesel under higher engine speeds. Around 11wt.% of oxygen content in the biodiesel properties leads to shorter ignition delay and improve the combustion efficiency, which in turn reduced the concentration of CO emission.

Figure 7. Effects of different renewable fuels and engine speeds on CO concentrations under constant engine load.
Figure 8 shows the HC concentration from the impacts of engine speeds and different biodiesel blends. The increasing engine speeds leads to reduce the HC concentration for all fuels tests. Furthermore, B100 reduced the HC concentration by 50% and 65% under low and high engine speeds, respectively. For other blends, B20 and B50 decreased HC concentration by 20% and 35%, respectively, compared to the diesel. This is due to the decrease the trapping of fuel in boundary layers and crevices as well as complete combustion [3, 8].

![Figure 8. Effects of different renewable fuels and engine speeds on HC concentrations under constant engine load.](image)

The level of NO\textsubscript{X} emission from the burning of different biodiesel blends is shown in Figure 9 under variable engine speeds and constant engine torque. The concentration of NO\textsubscript{X} emissions increased from the burning of neat biodiesel compared to the diesel. This trend because of high combustion temperature from burning of biodiesel blends with high engine speeds and flow velocity of the reactant mixture. In addition, the oxygen content in the fuel chemical structure could enhance the NO\textsubscript{X} formation inside combustion cycle [37]. On other hand, Figure 9 shows that the burning of diesel fuel inhibited the NO\textsubscript{X} formation compared with B100, B20, and B50 for variable engine speeds.
Figure 9. Effects of different renewable fuels and engine speeds on NO\textsubscript{X} concentrations under constant engine load.

The values of CO\textsubscript{2} emissions emitted during burning of different blends of biodiesel are shown in Figure 10 under variable conditions of engine speeds. The burning process of B100, B50, and B20 increased the CO\textsubscript{2} emissions with increasing the engine speeds, and the same trend was found with diesel fuel. The engine consumed high amount of fuel to increase the engine speed which result in higher fuel burn to generate the CO\textsubscript{2} emissions [6]. The burning of biodiesel blends produced slightly lower CO\textsubscript{2} emissions with increasing the engine speeds compared with conventional diesel fuel. This trend of biodiesel blends was found with variable engine loads and constant engine speeds.

Figure 10. Effects of different renewable fuels and engine speeds on CO\textsubscript{2} concentrations under constant engine load.
The level of PM concentration from burning of different blends of biodiesel is shown in Figure 11 under 44 kN/m² of engine load. The concentration of PM highly reduced with adding of biodiesel to the fuel blends than to the diesel [38]. Furthermore, it is clear that the PM concentration reduced under medium engine speeds for all fuels tests compared with low and high conditions of engine speeds. These trends give us indication that PM concentrations affect by the engine operation conditions. The burning of B20, B50 and B100 decreased the PM concentration by 16.847, 28 & 43.34%, respectively, compared with diesel fuel.

![PM concentrations vs Engine speed](image)

**Figure 11.** Effects of different renewable fuels and engine speeds on PM concentrations under constant engine load.

### 4. Conclusions

The effects of variable conditions of engine loads and speeds and different blends of biodiesel (B100, B50, and B20) on engine emissions and PM concentration were studied. The interestingly point was that the higher oxygen content in biodiesel blends properties decreased the engine emissions under variable engine loads and speeds. Besides, the CO concentration declined from burning of biodiesel blends with high load, while increased CO concentration under low engine load. B100 combustion significantly reduced the unburnt HC emissions compared with B50, B20, and diesel. It was observed that NOX emissions increased from the burning of fuel blends (B100, B50, and B20) under increasing the engine speeds. The emissions of CO and HC decreased both by 50% in average from biodiesel blends under increasing the engine speeds. It can be concluded that the PM significantly decreased from biodiesel blends under medium condition of engine loads and speeds.

### References

[1] Fayad, M.A., Herreros, J.M., Martos, F.J. and Tsolakis, A 2015 *Environmental science & technology* 49(19) pp11967-11973
[2] Chaichan, M.T., Kazem, H.A. and Abed, T.A. 2018 *Environment, Development and Sustainability* 20(2) pp589-603
[3] Dhahad, H.A., Chaichan, M.T. and Megaritis, T., 2019 *Energy* 181 pp1036-1050
[4] Song J, Zhang C. 2008 Proceedings of the Institution of Mechanical Engineers Part D: Journal of Automobile Engineering 222 pp2487-96
[5] Dhahad, H.A., Ali, S.A. and Chaichan, M.T. 2020 *Case Studies in Thermal Engineering* 20 pp100651
[6] Chaichan, M.T., 2018 Thermal science and Engineering Progress 7 pp 45-53
[7] Fayad, M.A. 2020 Thermal Science and Engineering Progress 19 pp 100621
[8] Özesen A, Canakci M, Turkcan A, Sayin C. 2009 Fuel 88 pp 629-36
[9] Dhahad, H.A. and Chaichan, M.T., 2020 Thermal Science and Engineering Progress 18 pp 100535
[10] Zheng M, Mulenga M C, Reader G T, Wang M, Ting D S K, Tjong J. 2008 Fuel 87 pp 714-22
[11] Sadeghinezhad E, Kazi SN, Badarudin A, Oon CS, Zubir MNM, Mehrali M. 2013 Renewable and Sustainable Energy Reviews 28 pp 410-24
[12] Fayad, M.A. 2019 Energy Sources, Part A: Recovery, Utilization, and Environmental Effects pp 1-11
[13] Baweja, S., Trehan, A. and Kumar, R. 2021 Fuel 292 pp 120346
[14] Justin Abraham Baby, S., Suresh Babu, S. and Devarajan, Y., 2021 International Journal of Ambient Energy 42(3) pp 269-273
[15] Ganesan, S. and Devarajan, Y., 2021 International Journal of Ambient Energy 42(1) pp 11-14
[16] Rameshbabu, A. and Senthilkumar, G., 2021 Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 43(11) pp 1315-1328
[17] Fayad, M.A. and Dhahad, H.A. 2021 Fuel 286 p 119363
[18] Kannan, M., Balaji, R., Babu, R.S., Shende, C.B. and Selokar, A. 2021 Information Technology in Industry 9(1) pp 436-443
[19] Prakash, S., Abraham Baby, S.J. and Manikandan, K. 2021 International Journal of Ambient Energy 42(3) pp 292-296
[20] Fayad, M.A., Tsalokis, A. 2020 Renewable Energy 149: pp 962-969
[21] El-Kasaby M, Nemit-allah MA. 2013 Alex Eng J. 52(2) pp 141-9
[22] Islam, M.A., Rahman, M.M., Heimann, K., Nabi, M.N., Ristovski, Z.D., Dowell, A., Thomas, G., Feng, B., Von Alvensleben, N. and Brown, R.J. 2015 Fuel 143 pp 351-360
[23] Arbab, M.I., Varman, M., Masjuki, H.H., Kalam, M.A., Imtenan, S., Sajjad, H. and Fattah, I.R. 2015 Energy Conversion and Management 90 pp 111-120
[24] Fayad, M.A., Fernández-Rodriguez, D., Herreros, J.M., Lapuerta, M., Tsalokis, A. 2018 Fuel 229 pp 189-197
[25] Fattah, I.R., Masjuki, H.H., Kalam, M.A., Wakil, M.A., Ashraful, A.M. and Shahir, S.A. 2014 Energy Conversion and Management 83 pp 232-240
[26] Dhahad, H.A. and Fayad, M.A. 2020 Fuel 279 p 118384
[27] Hamza, N.H., Ekaab, N.S. and Chaichan, M.T. 2020 Alexandria Engineering Journal 59(3) pp 1717-1724
[28] 1. LINE, A., G. 1986 Guideline 2, Guideline
[29] Keating, E.L. 2007 CRC press.
[30] McWilliam, L., Megaritis, A. 2009 International journal of vehicle design 50(1-4) pp 107-123
[31] Fayad, M.A., Al-Ogaidi, B.R. 2019 Engineering and Technology Journal 37(10A) pp 384-390
[32] Chaichan, M.T., Al Zubaidi, D.S. 2012 Association of Arab Universities Journal of Engineering Science 18(1) pp 43-56
[33] Khanjani, A. and Sobati, M.A. 2021 Fuel 288 pp 119662
[34] Neer, A., Köylü, U.O. 2006 Combustion and Flame 146 pp 142-154
[35] Fayad, M.A., Tsalokis, A., Fernández-Rodriguez, D., Herreros, J.M., Martos, F.J., Lapuerta, M. 2017 Applied Energy 190 pp 490-500
[36] Balamurugan, G. and S. Gowthaman. 2021 Materials Today: Proceedings
[37] Fayad, M.A. 2019 SN Applied Sciences 1(9) pp 1-10
[38] Jung, Y., Hwang, J., Bae, C. 2016 Fuel 165 pp 413-424