Engine performance and PM concentrations from the combustion of Iraqi sunflower oil biodiesel under variable diesel engine operating conditions

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Abstract: The most desirable alternative fuels are biodiesel among several of alternative fuels to use in diesel engines. The biodiesel used in this study is sunflowers oil which derived from local renewable sources. Also, biodiesel considered a best alternative to conventional diesel because it clean and environment friendly. The experimental results showed that the biodiesel blends (B20, B50, and B100) increased the brake specific fuel consumption (BSFC) compared with pure diesel fuel. According to the results, it is indicated that the biodiesel blends reduced the brake thermal efficiency (BTE) and exhaust gas temperatures (EGT) during the combustion of B20, B50, and B100 for all engine operating conditions. The exhaust gas temperature and BSFC increased with increase the operating conditions of engine loads and speeds. The data indicated that PM concentrations reduced with biodiesel blends combustion compared with diesel under variable engine loads and speeds. Besides that the concentrations of PM reduced by 16.847, 28, and 43.34\% combustion of B20, B50, and B100, when compared with petroleum diesel under the same conditions of engine loads and speeds. The results give insight that the oxygen content in the biodiesel has favourable effect on reducing the PM concentrations.

Keywords: Biodiesel, BSFC, BTE, combustion, exhaust temperatures, PM.

1. Introduction

Oil crises have continued from 1970 until today, marking the beginning of the end of its reign [1]. If the researchers take into account the great damage that is caused by the burning of petroleum products on public health and the environment, in addition to greenhouse gases, humanity finds itself facing a critical decision to shift towards other types of clean and environmentally friendly alternatives [1, 2]. Researchers have tried many alternatives, such as using water-diesel suspension [3-5], adding nanoparticles to diesel [6-8], adding antioxidants to diesel [9-11], and the most important of these alternatives is adding biofuels to diesel [12, 13]. Biofuels compared to fossil fuels is cleaner and reduces greenhouse effect. Also, it is green and environmentally friendly fuel produced from sources of biomass and agricultural resources. Biodiesel can be used as a pure fuel without change in engine design and associated systems, such as lubrication and fuel injection. The amount of oxygen in the biofuel properties leads to improve the combustion of the fuel-air mixture and reduces the pollutants emitted, except for nitrogen oxides, whose concentrations increase relatively due to this abundance [14]. What
blame on biofuels that they are extracted from agricultural resources exploiting agricultural land and can also cause food lack. There are still many scientific studies working to solve this problem to provide sustainable biofuels. Biofuels can be produced from a large number of resources, perhaps the most famous of which is ethanol, produced from sugar cane, beet, and maize [15-17]. Converting agricultural crops into liquid biofuels harms the whole world. However, it was noticed that a significant growth in the use of this fuel, because of its low cost, and a large diversification of its production sources. Reducing the cost of producing any biofuel will increase the chances of consumer acceptance. From here led to the escalation of research to enhance the fuel quality used as well as reduce negative impacts of climate change and global warming. Several experimental studies have proposed the preparation of biofuels from waste raw of vegetable oil, biodiesel, cooking oil, methanol, and ethanol.

The oil produced from agricultural material is chemically converted to biodiesel by reaction of this oil with alcohol and surfactant. It is blended with diesel fuel at different ratios, and it can also be used as neat fuel. The output power of a diesel engine is lower when using pure biofuel compared to diesel due to the LHV of the latter is higher than that of the first [18-20]. However, the studies revealed different results, as many researchers [21-23] considered that the power deterioration can be compensated by the expected energy increase. Biofuels suffer from higher viscosity and density compared to diesel, which somewhat affects the properties of the injected mixture [24]. Murillo et al. [25] checked the use of 100% biofuel on 3-cylinder diesel engine performance. The results showed a decrease in the engine power, which reached up to 7.14% compared to operating the engine with diesel, while the decrease in the calorific value by 13.5% of biodiesel when comparison with diesel. Many studies and research have supported such a conclusion [26, 27]. Many scientific studies agreed that higher engine fuel consumption occurs when using biodiesel instead of diesel due to its low LHV. There are also other properties of biodiesel that affect its energy content, such as the cetane number that is less than diesel, while its viscosity is higher than diesel, in addition to its content of water, which depends on the quality and efficiency of the preparation [28-30]. Researchers prefer adding biodiesel to diesel in different proportions, so that this addition is useful in reducing pollutants and not harmful to the performance of the engine. Most of researchers suggested that the adding a surfactant to the fuel leads to improve mixing of the two fuels, prevent their separation, and increase the stability of the thread. Surfactant is added to the mixture in very limited rates that do not exceed 2%, and its effect on combustion is completely unimportant [31, 32].

Razzaq et al. [33] used waste cooking oil (WCO) in the production of biodiesel. The researchers indicated that the product has a lower heating value than diesel but has a higher density, viscosity, cloud point, and flash point. Researchers tested a mixture of biodiesel added to the diesel in different ratios from 10% to 50% on the performance of a CI engine operating at 3000 rpm. The results showed a decrease in BT from the mixtures of B50, B40, B30, B20, and B10 by 3.5%, 3.09%, 2.2%, 2%, and 1.45%, respectively. The BSFC increased from the burning of B50, B40, B30, B20, and B10 by 12.76%, 8.8%, 5.73%, 1.61%, and 18%, respectively. Ref. [34] examined the effect of produced from renewable sources such as cooking oil wastes (biodiesel) and Cryptococinum cohnii dinoflagellates. Many experiments were employed with a turbocharged diesel engine with variable loads. Biofuels were mixed with diesel in different percentages by 50%, 20%, and 10% of microalga oil methyl ester and 20% mixture of waste cooking oil methyl ester with petroleum diesel. Using bio-algae diesel caused an instantaneous reduction in the engine torque and cylinder pressure than to the diesel by as much as 4.5% for a 50% mix condition. BSFC increased and BTE decreased at higher loads compared to diesel as a result of the lower calorific value of biodiesel. The researchers concluded that adding biodiesel (extracted from microalgae derived from (C. cohnii) by 50% to diesel will improve fuel properties and reduce harmful emissions with little impact on performance, making it suitable for applied in transport sector in the application of diesel engines. The current study is a part of the challenge to reach the best types of locally biofuels produced. Biodiesel was extracted from Iraqi-origin sunflower oil. The preparation of this biofuel was done by using a chemical treatment with methanol and a catalyst to
remove the Glycerin in the oil and then treat the product to clean it from methanol and water. The final product of fuel was added to the diesel with multiple volume ratios and the effect of these additives on the performance of a direct injection diesel engine was studied. Therefore, the purpose of this study is to examine different biodiesel blends on the engine performance and particulate matter (PM) concentration variable conditions of engine loads and speeds.

2. Experiments and materials

2.1 engine setup and tools

Four cylinders, direct injection, diesel engine (Fiat engine) was used in this study. Table 1 lists the main properties of research engine [35]. The outline of the research engine and its accessories is shown in the schematic diagram of Figure 1. 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 [36, 37]. 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 [38]:

\[
PM \, in \, \left( \mu g/m^3 \right) = \frac{w_2 - w_1}{V_t} \times 10^6 \quad (1)
\]

Where: PM is the concentration of particulate matters (µg/m³), \(w_1\) is the weight of filter sample before operation in (g), \(w_2\) is the weight of filter sample after operation in (g), and \(V_t\) is the total volume of drawn air (m³).

The equation below was used to calculate the \(V_t\):

\[
V_t = Q_t \times t \quad (2)
\]

Where: \(Q_t\) is the rate of air flow through the equipment (m³/sec), while \(t\) (min) represented the time of sampling.

Table 1: Specifications of engine

| Engine type   | 4-cyl., 4-stroke |
|---------------|------------------|
| Engine model  | TD 313 Diesel engine rig |
| Combustion type | DI, water cooled, natural aspirated |
| Displacement | 8.666 L |
| Valve per cylinder | two |
| Bore | 100 mm |
| Stroke | 110 mm |
| Compression ratio | 17 |
| Fuel injection pump | Unit pump |
| Fuel injection nozzle | 26 mm diameter plunger |
| Hole nozzle | 10 nozzle holes |
| Nozzle hole dia. | 0.48 mm |
| Spray angle | 160° |
| Nozzle opening pressure | 40 Mpa |
2.2 Fuel 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. Table 2 presented the properties of biodiesel blends and diesel fuels that measured at laboratories of Chemical Engineering, University of Technology-Iraq. The Oxygen-born in the fuel blends was obtained in range between 5.87 and 11.1 and this is agreement with previous studies [39, 40].

Table 2: Specifications of tested fuels

| Fuel type | Caloric value (kJ/kg) | Density (g/cm³) | Viscosity (mm²/s at 27 °C) | Cetane No. | Flame point (°C) | Cloud point (°C) | Pour point (°C) |
|-----------|-----------------------|-----------------|---------------------------|------------|-----------------|-----------------|----------------|
| Diesel    | 44227                 | 810             | 4.23                      | 49         | 59              | -13.8           | -29            |
| B100      | 39873                 | 906             | 6.5                       | 38.6       | 239             | -3.7            | -12.4          |
| B50       | 40368                 | 877             | 4.7                       | 40.6       | 179             | -10.2           | -17.833        |
| B20       | 41654                 | 829             | 14.38                     | 42.9       | 112             | -11.78          | -24.68         |

2.3 Test procedure

Three blends of biodiesel (B20, B50 & B100) were tested in this study to operating the diesel engine with various operating condition of engine loads and speeds. The diesel fuel was the first fuel tested in the engine to get the reference results. Subsequently, the engine was run with different blends of biodiesel to obtain various results of emission and combustion for comparison with references fuel (diesel fuel). The fuel lines of the engine were cleaned after each test to present the real results with new fuel blends. The engine performance and particulate emissions were measured and analyzed under variable of operating condition of engine loads and speeds. The results obtained by equipment were recorded continually to obtain more confident results by averaged these results. The variation in the results of engine performance and PM emission emitted from burning of biodiesel blends were
compared with results obtained from the reference fuel of diesel to define the beneficial effect of renewable fuel combustion.

3. Results and discussion

It well known that biodiesel can be used as a blend with diesel fuel for different proportion and this agreement with previous studies [41-43]. The effects of brake mean effective pressure and fuel blends on the brake specific fuel consumption (BSFC) are shown in Figure 2. In general, it is clear that the BSFC decreased with engine loads for fuel blends and diesel. For biodiesel addition, the increase of biodiesel in the fuel blends leads to increase the BSFC for various engine loads (Figure 2). The lowest heating value of biodiesel leads to consume more biodiesel in the diesel engine. Higher feeding rate of biodiesel was needed to generate the same engine torque that produced from diesel fuel. The BSFC increased from the combustion of B20, B50 and B100 by 23, 27, and 35.7%, respectively, compared with regular diesel.

![Figure 2: Effects of engine loads and biodiesel blends on brake specific fuel consumption (BSFC).](image)

The effects of engine speeds and fuel type on BSFC are shown in Figure 3 for constant value of engine torque. The BSFC significantly increased for all fuel tests of biodiesel blends represented in B20, B50, and B100 with increasing the engine speeds. This is because of the lower values of heating and calorific in fuel properties of biodiesel which in turn increased the BSFC of biodiesel. These results are in agreement with most of prior works in the literature [44-46]. In contrast, the higher values of heating and calorific of conventional diesel fuel properties leads to improve the fuel economy of diesel fuel compared with the three blends of biodiesel (Figure 3).
The effects of biodiesel blends and BMEP on brake thermal efficiency (BTE) are shown in Figure 4. The value of BTE was 30.4% from diesel fuel combustion at full load. Furthermore, it can be noticed that the values of BTE were 28.8%, 27.9%, and 27% from the combustion of B20, B50, and B100, respectively, as presented in Figure 4. It is clear that the biodiesel blends produced lower values of BTE compared to the diesel under the same operating condition. The main reason for that is the lower heating value of biodiesel blends (Table 2) [47, 48]. At fuel engine load, it can be seen that the BTE decreased by 3.45% from the combustion of B100 compared with diesel fuel (Figure 4). The effects of variable engine speeds and biodiesel blends on BTE are shown in Figure 5. According to this Figure, the BTE is slightly lower from biodiesel blends compared with diesel fuel combustion during all engine speeds. The data from this figure showed that the trend of biodiesel blends have the same trend under variable conditions of engine speeds and loads (Figure 5).

**Figure 3:** Effect of fuel blends and engine speeds on BSFC.

The effects of biodiesel blends and BMEP on brake thermal efficiency (BTE) are shown in Figure 4. The value of BTE was 30.4% from diesel fuel combustion at full load. Furthermore, it can be noticed that the values of BTE were 28.8%, 27.9%, and 27% from the combustion of B20, B50, and B100, respectively, as presented in Figure 4. It is clear that the biodiesel blends produced lower values of BTE compared to the diesel under the same operating condition. The main reason for that is the lower heating value of biodiesel blends (Table 2) [47, 48]. At fuel engine load, it can be seen that the BTE decreased by 3.45% from the combustion of B100 compared with diesel fuel (Figure 4). The effects of variable engine speeds and biodiesel blends on BTE are shown in Figure 5. According to this Figure, the BTE is slightly lower from biodiesel blends compared with diesel fuel combustion during all engine speeds. The data from this figure showed that the trend of biodiesel blends have the same trend under variable conditions of engine speeds and loads (Figure 5).
Figure 4: Effect of fuel blends and engine loads on brake thermal efficiency (BTE).

Figure 5: Effects of fuel blends and engine speeds on brake thermal efficiency (BTE).

Higher and lower values of exhaust gas temperatures (EGT) from the combustion of biodiesel blends are presented in Figure 6 under different loads. The value of EGT increased under high engine loads for fuel blends and diesel. This is due to the increase the amount of fuel injected in the combustion cycle with increase the engine torque [45]. From Figure 6, it is clear that the diesel fuel combustion increased the exhaust gas temperatures, especially with high loads due to the higher value of heating. The temperature value in the exhaust gas was slightly lower from the combustion of B100, B50, and B20 than to the diesel fuel combustion (Figure 6). This could be due to the less burning gas temperatures resulted from the lower heating value inside combustion cycle [49, 50]. The variations of EGT from burning of biodiesel blends (B20, B50, and B100) under variable of engine speeds are illustrated in Figure 7. The results revealed that the EGT increased with increasing engine speeds. This could be due to the more fuel injected in the combustion cycle to obtain the same engine torque. The same trend of EGT was observed with increasing the engine speeds from the combustion of biodiesel blends. The higher heating value of biodiesel blends properties is the key reason for the slightly lower EGT produced from burning of different biodiesel blends than to the diesel fuel (Figure 7).
The concentrations of PM emission from the different combustion of biodiesel blends are shown in Figure 8 under variable engine loads and constant engine speed. The carbon soot particles represent the main component of PM which produced when insufficient oxygen in the fuel to react with all carbon. During the combustion process, the PM produced in the zone of fuel rich into the combustion cycle. A few differences of PM emission in low load level were found from biodiesel combustion (Figure 8). The levels of PM concentrations significantly reduced from biodiesel blends combustion than to the diesel fuel combustion. The PM concentration reached the maximum reduction from the neat biodiesel by 34.96% compared with diesel fuel under full engine load. Also, the smoke emission decreased from the combustion of biodiesel blends under variable engine loads. This is due to the
collective effect of complete combustion and free soot particles from oxygenated fuels (biodiesel blends) [51, 52]. It is reported in the prior studies that the oxygenated fuels decreased the smoke level and soot emission for different engine operating conditions [53-55].

**Figure 8:** Effect of fuel blends and engine loads on particulate matter (PM) concentration.

The findings from Figure 9 illustration the effect of biodiesel blends and engine speeds on the concentrations of PM. Adding biodiesel to the fuel blends significantly reduced the concentrations of PM for all operating conditions of engine speeds. It was observed that the B20, B50, and B100 decreased the PM concentrations by 16.847, 28, and 43.34%, respectively, compared with conventional diesel. These outcomes gives a good indication that the PM concentrations affected by the engine operation mode.

**Figure 9:** Effect of fuel blends and engine speeds on particulate matter (PM) concentration.
4. Conclusions

The effect of different biodiesel blends on the engine performance and particulate matter (PM) concentrations was investigated in this study under various engine loads and speeds. It can be concluded that the B20, B50, and B100 increased the fuel consumption by 23, 27, and 35.7%, respectively, when compared with diesel fuel, this was clearer with maximum engine load. It was found that the brake thermal efficiency (BTE) of the engine decreased with addition of biodiesel percentages to the fuel blends. Moreover, the minimum value of BTE was obtained from the combustion of B100 by 3.45%. For various engine loads and speeds, the exhaust gas temperatures (EGT) decreased from biodiesel blends combustion than to the conventional diesel fuel. In case of PM, the total concentrations of the PM were inhibited during the biodiesel blends combustion. The oxygen content in the fuel blends enhances...
the oxidation rate of PM under variable engine operating conditions. Also, it was found that biodiesel (B100) had the best reduction of PM by 34.96% compared with diesel fuel under high engine load.

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