The Impact of Methanol Addition to the Biodiesel-Diesel Blends on the Performance and Exhaust Emissions of the CI Engines

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Abstract. One of the major problems in the contemporary world is pollution. The major contribution in this area comes from automobile emissions and industries. Diesel being one of the major fuels is also a major contributor in adding harmful pollutants into the atmosphere. In order to meet the stringent emission norms, the polluting components in the fuels need considerable reduction. Fuel characteristics play a major role in engine efficiency and engine emissions directly or indirectly. In the present work, an experimental investigation of the effect of adding methanol to the diesel-biodiesel blends on the performance and combustion characteristics of the diesel engine has been performed. Three different concentrations of methanol are used; namely 5%, 7%, and 10% of the overall mixture volume, while, biodiesel concentration has been fixed to eliminate its effect on the results. The results revealed that using methanol as an additive to the diesel-biodiesel blends prominently improved brake power, decreased brake specific fuel consumption (BSFC) and increased brake thermal efficiency (BTE) of the engine. CO, HC, and NOx emissions have shown a slight decrease compared to the corresponding neat diesel and diesel-biodiesel at the same loading and engine speed conditions.

Key words: methanol, diesel-biodiesel blends, diesel engine, exhaust emissions.

1. Introduction

Substitutive fuels for the internal combustion engines are becoming more important due to declining oil resources and the environmental impact of the exhaust emissions from the petroleum fueled combustion engines [1]. Biofuels represent one of the best known substitutive resources to the traditional fossil fuels for reducing the harmful exhaust emissions [2]. Among these biofuel alternatives, biodiesel is receiving increased interest as a fuel for the compression ignition engines. This is due to the attractive properties of
biodiesel such as the renewable resources, the possibility of biodiesel direct usage in the diesel engines without the need for further engine modifications [1], the relatively high degree of solubility of biodiesel in diesel [3], safe storage, and most importantly, the low toxic effect of the exhaust emission compared to conventional diesel [4]. Biodiesel is a mono-alkyl ester made from long chain fatty acids through a transesterification reaction of triglycerides derived from available raw materials, abundant and renewable, such as vegetable oils and animal fats. During reaction, these oils are heated by alcohol in the presence of a catalyst (usually NaOH), which leads to the formation of alkyl ester and glycerin as a by-product [5]. However, the main problems associated with the use of biodiesel are less engine break power, and higher brake specific fuel consumption because of the low thermal values of biodiesel, in addition to higher density and viscosity compared to the corresponding diesel products [4]. Nitrogen oxides also increase with the use of higher-fuel oxygen (biodiesel) [6]. Thus partial addition of biodiesel to the conventional diesel in the form of blending is more preferred than complete replacement [3]. Hence, a variety of studies have been conducted for investigating the effect of blending diesel with biodiesel on the performance and exhaust emissions of the diesel engines [7–11].

Alcohols on the other hand, are other forms of renewable biofuels that have been studied extensively in the form of additives rather than complete replacements to diesel [12–15]. Nevertheless, compared to diesel, alcohols are characterized by low cetane number and higher latent heat of vaporization preventing them from replacing the diesel entirely [3]. Another drawback of alcohols is the incomplete miscibility to diesel [16] leading to relatively heterogeneous mixtures rather than uniformly homogeneous blends resulting from diesel/biodiesel blending. Thus, one of the methodologies proposed to overcome the above problems is the use of tri-mixtures of diesel-biodiesel-alcohol blends rather than binary mixtures [17]. In this method, the biodiesel will act as an emulsifying agent between the diesel and alcohol leading to a more homogeneous and relatively stable blend [18]. Consequently, this type of blends has also been investigated extensively [18–24] to comprehend the effect of different concentrations of the three components on the performance and exhaust emissions of the compression ignition engines.

Hence, the objective of the present work is to investigate the enhancement of engine performance and exhaust emissions when fueled with diesel-biodiesel blends in the presence of methanol as an additive in different proportions. Biodiesel concentration in the blend is fixed to highlight the effect of both diesel and methanol concentrations on the results.

2. Experimental Work
2.1 Fuel Preparation
Both diesel and methanol where collected and directly used in their standard forms, with the first being obtained from Al-Durra Refinery in Baghdad and the latter being purchased from the local markets. Conversely, biodiesel is produced from sunflower oil through the reaction of methanol and NaOH as a catalyst. After separating biodiesel from glycerin, it was washed up and purified. On the other hand, the blends have been prepared in lab prior to experiments. Four volumetric proportions of the blends were prepared by high speed mixing of the basic components, i.e. diesel, biodiesel, and methanol. The diesel content in each of these blends is fixed to 80% of the total mixture by volume, while, methanol content is varied as 0%, 5%, 7%, and 10%, with biodiesel accounting for the remaining portion. The basic physical properties of all the base fuels and the resulted blends have been evaluated in-lab and summarized in Table 1. For avoiding confusion, and for easier characterization purposes, the prepared blends have been annotated by symbols based on the first letters of each of the base fuels, i.e. (D) for diesel, (M) for methanol, and (B) for biodiesel, and numbers for representing the concentration of each substance in the blend. For example, the symbol D80B15M5 represents a blend with 80% diesel, 15% biodiesel, and 5% methanol respectively.

| Properties | Diesel | Sunflower biodiesel | Methanol | D80B20 | D80B15M5 | D80B13M7 | D80B10M10 |
|------------|--------|---------------------|----------|--------|----------|----------|----------|
| Approx. formula | C_{16}H_{34} | C_{19}H_{36}O_{2} | CH_{3}OH | 2.8    | 4.92     | 1.15     | 3.22     | 3.03     | 2.96     | 2.84     |
2.2 Experimental Setup and Procedures

Figure 1 shows the photograph and schematic diagram of the TD212 test bed on which all the experimental work has been conducted. The test bed consists of a single-cylinder, compression ignition engine connected to a hydraulic variable fill dynamometer with a maximum power of 7.5 kW at 7000 rpm. The specifications of the engine are listed in Table 2. Additionally, TEXA exhaust gas analyzer was used for reading the NOx, HC and CO emissions from the engine during the tests.

Table 2: Engine Specifications.

| Manufacture       | TecQuipment Ltd. UK          | Model | TD212                             |
|-------------------|------------------------------|-------|-----------------------------------|
| Type              | Direct injection, 4 stroke   |       |                                   |
| No. of cylinders  | 1                            |       |                                   |
| Max. power        | 3500 W                       |       |                                   |
| Bore              | 69 mm                        |       |                                   |
| stroke            | 62 mm                        |       |                                   |
| Method of cooling | Air cooled                   |       |                                   |
| Max. speed        | 3600 rpm                     |       |                                   |
The engine was first run fueled with diesel to define the baseline parameters as well as for the warm up purposes. Engine performance parameters those have been measured are brake power, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE). The engine rotational speed was set to 1500 rpm, at different brake power of the engine. For data logging, Versatile Data Acquisition (VDAS-F) data control system was used. Emission analysis was also conducted at constant speed and different brake power.

3. Results and Discussions

3.1. Engine Performance

3.1.1. Brake Thermal Efficiency

The brake thermal efficiency of the internal combustion engine is the ratio of the brake power output of that engine to the maximum released energy due to complete combustion of the fuel used [25]. Hence, it has been evaluated for testing the effect of the different blends on this efficiency. Figure 2 shows the variation of brake thermal efficiency with the brake power of the engine for neat diesel, D80B20, D80B15M5, D80B13M, and D80B10M10 blends respectively. The brake power is ranging from 0.5 to 3.0 kW with the rotational speed being set to 1500 rpm. The proportionality of the brake thermal efficiency with the brake power is obviously apparent in the figure for all the tested fuels. From the figure, it can also be seen that with the increase of methanol percentage in the blend, the thermal efficiency is increased, this is due firstly to the increase of oxygenated fuels (both methanol and biodiesel) which in turn leads to combustion efficiency enhancement, and secondly to the lower boiling point of methanol compared to diesel which enhances spray atomization [13].

Additionally, the heat losses are decreased due to the resulting decrease in flame temperature by increasing methanol content in the blend. Furthermore, fuel evaporation continues during the power stroke as the latent heat of vaporization of methanol is higher than that of diesel. Hence, the fuel absorbs more heat from the cylinder for completing evaporation; this in turn decreases the heat loss from the engine as stated above. All these factors result in higher break thermal efficiency of the engine when increasing methanol content in the fuel mixture. This in fact, is in agreement with the findings in literature [13,19,24].

3.1.2. Brake Specific Fuel Consumption

The brake specific fuel consumption (BSFC) is defined as the rate at which the fuel is consumed to produce a unit brake power [26]. Generally, BSFC of the engine when fueled with alcohol blended diesel is slightly higher than that of the engine fueled with neat diesel and biodiesel-blended diesel [17,23,24,27,28]. This is because of the lower heating value of alcohol compared to diesel and biodiesel. This lower heating value of alcohol came from the oxygen content in alcohol which does not contribute to the heat generation during combustion inside the cylinder and it normally increases alcohol fuel consumption and its blends. However,
this is not the case in all times, where sometimes the lower energy content of alcohol – especially lower alcohols – with the high consumption rate compared to diesel and biodiesel causes the BSFC to be higher than those of the corresponding diesel and biodiesel fuels [29]. This in addition to the effect the engine operating conditions – such as load and rotational speed – on the fuel consumption rate. Therefore, Figure 3 shows the variation of BSFC with the brake power of the engine for neat diesel, D80B20, D80B15M5, D80B13M, and D80B10M10 blends respectively. From the figure, it can be seen that the BSFC of all the fuels under investigation decreases with increasing the load. Besides, a slight increase in the BSFC is noticed with increasing methanol content in the blends due to the reasons stated above. Likewise, the low density and viscosity as well as the low cetane number of methanol can be considered as reasons for this kind of behavior.

![Figure 3: Brake specific fuel consumption versus brake power.](image)

3.2. Exhaust Emission Characteristics
3.2.1. Hydrocarbon (HC) Emission
The variation of hydrocarbon (HC) emission with brake power for neat diesel, D80B20, D80B15M5, D80B13M, and D80B10M10 blends is shown in Figure 4. It is believed that using the oxygenated fuels – such as biodiesels and alcohols – will enhance the combustion efficiency by supplying the oxygen required for promoting combustion. This in turn, decreases the presence of unburned hydrocarbons in the product gases. This is the case shown in Figure 4 for the tested fuels, which is also in agreement with the findings published in literature [16,20,23]. However, some literature [17,30] have shown dissimilar behaviors of HC emission from diesel fuels when blended by alcohols.

![Figure 4: HC emission versus brake power.](image)
3.2.2. Carbon monoxide (CO) emission

Figure 5 shows the variation of CO emissions of the neat diesel, D80B20, D80B15M5, D80B13M, and D80B10M10 blends respectively with engine load in the form of brake power. For the same reasons of higher oxygen content, the CO emission in the exhaust is inversely proportional to the methanol content in the fuel. Since, the higher the oxygen, the higher is the probability of complete combustion and the lower is the tendency of CO formation [31]. However, different level of CO emission among the blends with additives can be explained by the physical and chemical properties of the additives.

![Figure 5: CO emission versus brake power.](image)

3.2.3. Nitrogen Oxide (NOx) Emission

NOx are formed due to the oxidation of nitrogen from the intake air in the combustion process. The variation of NOx formation in the exhaust gases with the brake power is shown in Figure 6. The amount of NOx formed, mostly depends on the combustion temperature, the oxygen concentration and residence time for the reaction to take place [32]. D80B20 showed higher NOx all through the engine test as because it contains higher level of oxygen. However, though ethanol has got higher oxygen content, D80B15M5, D80B13M7 and D80B10M10 showed lower NOx which can be explained by their lower calorific value and higher heat of evaporation which resulted in lower in-cylinder temperature.

4. Conclusion

In this study a comparative evaluation of the effect of adding methanol to the diesel-biodiesel on the performance and combustion characteristics of the diesel engine. Methanol addition took place in three different proportions; namely 5%, 7%, and 10% of the overall mixture volume, while, biodiesel concentration has been fixed to eliminate its effect on the results. Through the analysis, the following conclusions came out:

The addition of methanol led to combustion enhancement at constant engine rotational speed. This enhancement is shown in the higher brake thermal efficiency, and lower combustion exhaust emissions. Among the blends, (D80B20M10) blend, showed highest improvement through its less density and viscosity.

Regarding emission characteristics additives showed quite a good development of CO, HC and NOx emission. HC and CO emissions decreased for higher oxygen content and NOx decreased for lower calorific value and higher latent heat of evaporation of the additives. Methanol is quite effective regarding emission and performance even when there is used about 10% as additive to biodiesel-diesel blend.
Figure 6: NOx emission versus brake power.

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