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Evaluating Water–Diesel Emulsion (7% and 17%) on the Performance of a Four-Cylinder Diesel Engine

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Abstract

Diesel engines are renowned for their high efficiency and fuel economy. In recent developments, water-diesel emulsions have been proposed as an alternative fuel to enhance engine performance across various operational settings. This study focused on assessing the impact of different water-diesel emulsion ratios, specifically 7% and 17%, on the performance of a water-cooled, four-cylinder diesel engine operating continuously at 1600 rpm. The experiment was conducted using a completely randomized design (CRD) to evaluate the effects of fuel type and load. Significant differences between means were determined using the least significant difference (LSD) test at $p < 0.05$. The results showed that using a 7% water–diesel emulsion increased thermal efficiency by 5.81% compared to neat diesel. This improvement was accompanied by an approximate 7% rise in brake-specific fuel consumption (BSFC), while exhaust gas temperature decreased by 13.45%. In contrast, increasing the water content to 17% led to only a slight improvement in thermal efficiency (0.43%), while exhaust gas temperature decreased by 18.52%, indicating a cooling effect during combustion. However, this was accompanied by a considerable increase in brake-specific fuel consumption (26%), which may negatively affect overall engine performance. Overall, the findings suggest that a 7% water/diesel ratio provides a more advantageous balance between performance and emissions reduction under the tested operating conditions.

Keywords: Diesel engine, alternative fuel, Water/diesel emulsion , performace

Introduction

The diesel engines are widely used because of their high thermal efficiency and the high energy density of the fuel used, which makes improving their performance a research area of great importancene remains a predominant source of mechanical power. Its significance stems from its capacity to convert the chemical energy in fuel into mechanical energy through combustion within the engine. Factors such as fuel availability, cost, and combustion characteristics are critical considerations for users. Consequently, while fuel combustion provides valuable energy, Diesel fuel is characterized by a higher energy density compared to gasoline, which positively impacts fuel efficiency and engine performance, especially in applications requiring high power output such as heavy vehicles and industrial equipment. Diesel engines rely on the principle of compression ignition, meaning the combustion process within the cylinder directly affects thermal performance and operating efficiency. However, the overall performance of these engines is highly dependent on fuel properties and combustion conditions, prompting researchers to focus on developing alternative fuels to improve performance and increase efficiency[1] . The pursuit of alternative and sustainable energy sources has become crucial for suitable alternatives to mitigate global warming is in important topic that has received attention within the global Sustainable Development goals given its role in reducing environment impacts and improving the sustainability of energy sources[2].

Many research efforts have focused on developing renewable alternatives to fossil fuels, with the aim of reducing harmful environmental impacts and providing sustainable fuel that can be used efficiently in internal combustion engines [3].

Recent studies have explored diverse alternative fuels for conventional diesel engines to enhance engine performance. Similarly, study[4] demonstrated the potential of diesel–biodiesel–water emulsions as a substitute for traditional diesel. Study [5] reported that biodiesel derived from transesterification of various feedstocks can serve as a sustainable transportation fuel, positively affecting engine performance. Additionally,study[6] systematically reviewed hydrogen-diesel dual fuel technology, revealing that hydrogen enrichment enhances engine performance. Abdullah and Kadhim[7] conducted a pilot study to evaluate the performance of a diesel engine running on a butanol-acetone mixture with diesel fuel at two different fuel levels. It was observed that the butanol-acetone mixture did not show a significant improvement in performance, however, it demonstrated a significant reduction in carbon dioxide, hydrocarbon, and nitrogen oxide emissions.Water–diesel emulsion is a significant development in the field of alternative fuels, as it can be easily used without requiring engine modifications. This type of fuel helps improve combustion by enhancing thermal efficiency and performance. Its ease of use in current operating systems makes it the most scientifically suitable option for improving thermal efficiency and reducing overall temperature [8].

Studies show that the use of water emulsions in diesel engines influences engine performance in various ways. Hosien and Sobati [9] reported that using a low water emulsion (2–5%) led to a reduction in torque and braking power, a conclusion supported by Seifi et al.[10] . Conversely, more recent studies [4,8,11] observed an improvement in thermal efficiency with decreased specific fuel consumption, while Hassan et al.[12] suggested that significantly increasing water content might reduce performance and increase fuel consumption.

The increasing global demand for fossil fuels and the limited availability of conventional energy resources have highlighted the need to improve fuel utilization efficiency in diesel engines. This has encouraged research into alternative fuel strategies that can enhance engine performance while reducing reliance on diesel fuel.

Therefore, the main objective of this study is to evaluate the performance of a diesel engine fueled with water–diesel emulsions at different mixing ratios (7% and 17%) under various engine load conditions.

Material and methods

Diesel fuel was taking from local fuel stations in Baghdad. Deionized water and the surfactants Span 80 and Tween 80 were procured from Loba Chemie Pvt. Ltd (India) for emulsion preparation. Two distinct emulsions were formulated in the laboratory through mechanical homogenization, a low-energy mixing technique designed to produce relatively stable emulsions with varying water ratios at room temperature [11]. To prepare the emulsion, the oil phase (diesel + Span 80) was mixed for one minute before adding the aqueous phase (water + Tween 80). The aqueous phase was then incorporated into the oil phase and mixed using a mechanical homogenizer for three minutes. Two emulsions were produced: one composed of 91% diesel, 7% water, and 2% surfactants (84% Span 80 and 16% Tween 80), and the other composed of 81% diesel, 17% deionized water, and 2% surfactant.The fuel types in the present study are shown in Figure 1.

Figure 1. Fuel types used in the present study: (A) Pure diesel, (B) water diesel emulsion7%, (C) water diesel emulsion17%.

Surfactant percentages were calculated on volume basis. The stability of the emulsions was monitored over the first 24 hours, during which no separation occurred. The emulsion remained stable for 30 days without any component separation. Minor separation or surfactant precipitation was observed after 35 The emulsion was prepared with a required HLB (Hydrophilic-Lipophilic Balance) of 6. The HLB value for Tween 80 was calculated using the following formula [13]:

Tween80% = 100(x -HLB Span) / (HLB Tween80-HLB Span80) ……… (1)

Where, x =required HLB , HLBTween80 = 15

HLP Span80 = 4.3

Table .1 properties of fuel

Property	Diesel pour	W/D 7%	W/D 17%
Density (g/cm^3)	0.8275	0.8365	0.84771
Viscosity (40 C^0)	2.765	3.7142	5.18425
Pour point (C^0)	-15	-15	-18
Flash point (C^0)	63	64	67
Calorific value KJ/KG	42889.5	39996.5	35319.8

Engine:

The engine used was a Korean-made, four-cylinder, four-stroke water cooled, Table 2 presents the engine specifications after engine preparation, it was started at 1600 rpm using pure diesel fuel under 0%, 50%, and 100% loads. Readings were taken at each load, including fuel consumption, exhaust temperature, and emissions. The experiment was repeated with 7% and 17%

emulsified fuels, taking into account changing the fuel filter with each fuel type.

Table .2 the engine specifications

Engine Type	Kia Bongo (Korean)
Engine Model	J2 2701
Displacement	2694 cm^3
Stroke	95 mm
Cooling System	Water-cooled
Bore	95 mm
Maximum Power	80 hp
Maximum Torque	16.8 N.m

Test procedure

The engine was first tested with pure diesel fuel, with the speed set to 1600 rpm and the engine allowed to run for 15 minutes to reach stabilization. After stability was achieved, fuel consumption and exhaust-temperature readings were taken with no load applied. A 50% load was then applied, and new readings of fuel consumption, temperature, current, and voltage were taken after the electric heaters equivalent to the load were operated; brake power was subsequently calculated from Equation (2),as brake power for the engine [14]:

$$P = V \times I \times P_F/1000 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, P =Electrical power (kW).

V = Voltage (potential difference) (V).

P_F = Power factor (%)

The procedure was repeated at 100% load, with all measurements recorded again. When 7% and 17% emulsified fuels were used, the fuel filter was changed and the engine was run for 10 minutes to purge the previous fuel. The entire sequence was then repeated for each fuel type. Once all data were collected, specific brake fuel consumption and brake thermal efficiency were calculated using Equations (2) and (3) as reported [14] .

$$BSFC = \dot{m}_f / BP \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\eta_{bth} = BP / (\dot{m}f \times LCV) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where,

BSFC = Brake specific fuel consumption (kg/kW.hr) .

$\dot{m}_f$ = fuel consumption (kg/h).

BP = Brake power (kW).

η_{bth} = Brake thermal efficiency (%) .

LCV = lower calorific value (kJ/kg)

The collected data were analyzed with a statistical system to assess the effects of fuel type and load at 1600 rpm. Factorial experiment was employed, with treatments randomized. Differences were evaluated using the Least Significant Difference test [15].

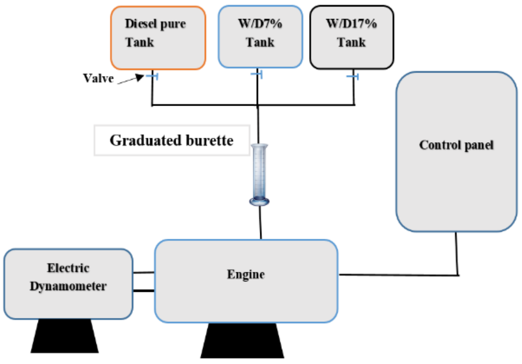

Figure .2 Schematic diagram of engine testing

Results and Discussion

Brake specific fuel consumption

Figure 3 depicts the effect of fuel type and load on brake specific fuel consumption (BSFC) at a constant speed of 1600 rpm. The mean values indicate that BSFC increases with increasing water content in diesel fuel. The emulsions showed statistically significant increases ($p \leq 0.05$) of 8% and 26% for W/D7% and W/D17%, respectively, compared to pure diesel. These differences are clearly illustrated in the figure.

Furthermore, BSFC decreased with increasing engine load. This trend can be attributed by improved engine efficiency at higher loads, where a larger portion of the fuel energy is converted into useful work, reducing the relative effect of frictional and heat losses. As the load increases, combustion becomes more stable and complete due to better in-cylinder conditions, resulting in improved fuel utilization. These findings are consistent with previous studies [12].

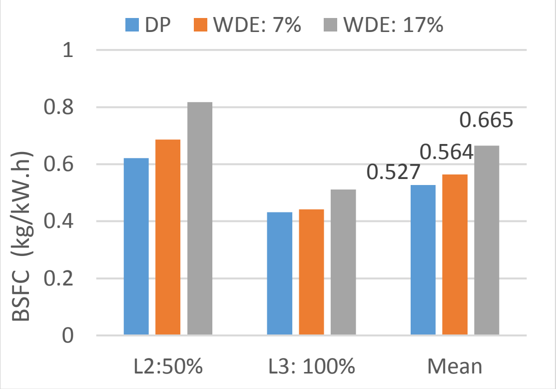

Figure 3. Fuel Type vs. BSFC

Brake thermal efficiency

Figure 4 illustrates the effect of fuel type and load on brake thermal efficiency (BTE). The results show statistically significant increases ($p \leq 0.05$), as the 7% W/D emulsion recorded the highest average BTE of 17.29%, representing a relative increase of 5.41% compared to pure diesel. The 17% W/D emulsion recorded 16.41%, a slight improvement of 0.43%, suggesting that optimal water content enhances thermal efficiency. The increase in BTE at 7% W/D is mainly attributed to the micro-explosions phenomenon, which enhances fuel atomization and combustion efficiency. This is consistent with findings by [11], who demonstrated that a small water addition, such as 8%, boosted BTE, whereas a higher water percentage, like 16%, caused a slight increase or stabilization of BTE under certain load conditions. Regarding engine load, brake thermal efficiency was significantly affected by increasing load, thermal efficiency improved as engine load increased from 50% to full load, due to better combustion conditions and improved conversion of thermal energy into mechanical energy. These findings are consistent with [16].

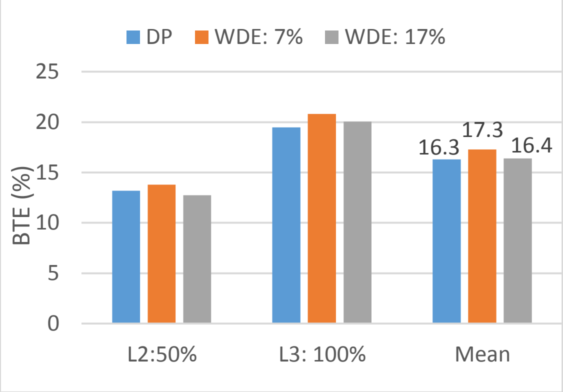

Figure 4. Fuel Type vs. Load on BTE

Exhaust gas temperature (EGT)

Figure 5 illustrates that the type of fuel has a statistically significant effect ($p \leq 0.05$) on exhaust gas temperature (EGT). The mean values show that both emulsions (7% W/D and 17%W/D) significantly reduced EGT compared to conventional diesel fuel, with decreases of 13.45% and 18.52%, respectively. These differences are clearly indicated in the figure.

This reduction is due to the water content's heat absorption in the emulsion. The latent heat of water helps to lower the combustion temperature during evaporation. The decrease in combustion temperature arises from the fine water droplets distributed in the water–diesel emulsion, acting as heat absorbers during combustion. These results are consistent with [17]. Furthermore, engine load had a statistically significant effect on exhaust gas temperature. EGT increased with load because the engine required more fuel to generate additional power under higher load conditions [18].

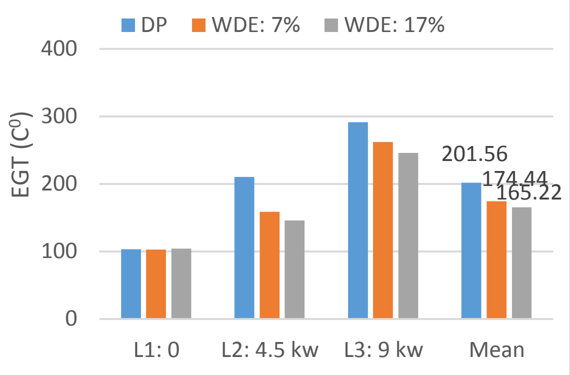

Figure 5. Fuel Type vs. Load on EGT

Conclusion

This study aimed to evaluate the impact of water–diesel emulsions on engine performance, with the goal of reducing dependence on fossil fuels and assessing the potential of emulsified fuels as a cost-effective and sustainable alternative. The results demonstrated that the 7% W/D emulsion achieved the best balance in engine performance. Thermal efficiency increased by 5.81% compared to pure diesel, while the brake specific fuel consumption increased by 7%. A noticeable reduction in exhaust temperature was also observed.

In contrast, the 17% W/D emulsion, a slight decrease in thermal efficiency of 0.45% was recorded compared to pure diesel, accompanied by a 26% increase in brake specific fuel consumption. A decrease in exhaust temperature was also observed.

Therefore, the 7% W/D emulsion is considered optimal under the studied conditions. The findings suggest that water–diesel emulsions can be a promising option for improving engine performance and enhancing fuel utilization characteristics**.**

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