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Impact of partial alteration of diesel fuel on the performance and regulated emission of a diesel engine

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ABSTRACT

Biodiesel has become one of the promising solutions for the future energy crisis. This study aims to assess the effect of alteration of fuel (replacing diesel with biodiesel) on the performance and regulated emission in a diesel engine. Biodiesel blends (WCB20) was prepared by mixing 20% of waste cooking oil biodiesel with 80% diesel fuel using a homogeneous mixture. The performance and regulated emission of WCB20 have been evaluated in a multi-cylinder diesel engine at various speeds with a full load condition and compared with diesel fuel. The results indicated that WCB20 offers 6.52% less brake power and 9.01% lower brake thermal efficiency whereas, 36.15% and 32.16% higher BSFC and BSEC in comparison to diesel fuel, respectively. However, regulated emission results showed that WCB20 significantly decrease carbon monoxide, particulate matter, and hydrocarbon by 38.93%, 15.46%, and 21.20% respectively but slightly increase the NO_x emission (13.79%). Finally, it can be concluded that partial alteration of conventional diesel fuel using 20% waste cooking oil biodiesel can indicatively reduce the harmful emission.

1. Introduction

Transportation emissions are the main causes of the deterioration of air quality in urban areas. It is also largely responsible for respiratory health problems [1]. The rapid increase in the number of vehicles on the road has resulted in a significant increase in polluted air in recent years. Fuels obtained from fossil fuels have long been the primary source of energy in the transportation and equipment industries, due to their superior energy output, rapid burning qualities, and widespread availability [2,3]. Unfortunately, the depletion of natural resources, environmental issues and increasing price of petroleum products have persuaded researchers to quest alternative energy sources [4,5]. Therefore, researchers are developing new alternative energy that has renewable and sustainable characteristics, is economically competitive, technically feasible and environmentally friendly. Thus, biofuel fulfils most of these criteria. Biofuel is feasible, clean energy, non-detrimental substance and produces a small number of harmful fumes than diesel fuel [6]. Biodiesel, a fuel derived from lipid, might be the most promising fossil fuel replacement to abate global reliance on fossil fuels and very few emissions of environmental pollutants without modifying a vehicle's engine [7]. Unlike diesel fuel, biodiesel is not explosive or combustible, and it possesses qualities that are similar to those of diesel fuel [8].

Biodiesel is also biodegradable, non-toxic, renewable, and environmentally beneficial [9,10]. Biodiesel is able to enhance engine performance and reduce exhaust emissions as well as smoke opacity compared with diesel fuel [11,12]. Unfortunately, the common sources of biodiesel such as rapeseed, palm, coconut, sunflower, jatropha curcas, peanut, cotton, neem, moringa oleifera, rubber, mahua, jojoba and castor are obsolete recently due to the high cost of the feedstock [13]. According to a calculation made by Haas et al. [14], the cost of refined oil occupies 88% of the gross cost of biodiesel. The use of less-expensive raw material such as waste cooking oil, crude vegetable oil and yellow grease are more preferred for biodiesel production.

Waste cooking oil has become an attractive feedstock as an alternative fuel for diesel engines. However, the performance and exhaust emission produced by waste cooking oil biodiesel still need to be investigated before utilisation in a diesel engine. Thus, the waste cooking oil biodiesel (WCB) is used and blended with diesel fuel to alter the

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Table 1
The characteristics of the test fuels used in this research.

Properties	WCB100	Diesel	ASTM D6751	EN 14,214
Kinematic Viscosity at 40 °C (mm^2/s)	5.04	3.23	1.9–6	3.5–5
Density at 15 °C (kg/m^3)	879.70	827.20	–	860–900
Higher Heating Value (MJ/kg)	38.66	45.30	–	–
Oxidation Stability (h)	0.47	–	3 min	6 min
Acid Value (mg KOH/g)	0.59	–	0.5max	0.5 max
Flash Point (°C)	180.0	68.50	130 min	120 min
Pour Point (°C)	–	0	report	report
Cloud Point (°C)	7	8	report	report
CFPP (°C)	−3	5	report	report
Cetane Number	53	48	47 min	51 min
Iodine Number	93.42	–	–	–
Saponification Value	195	–	–	–

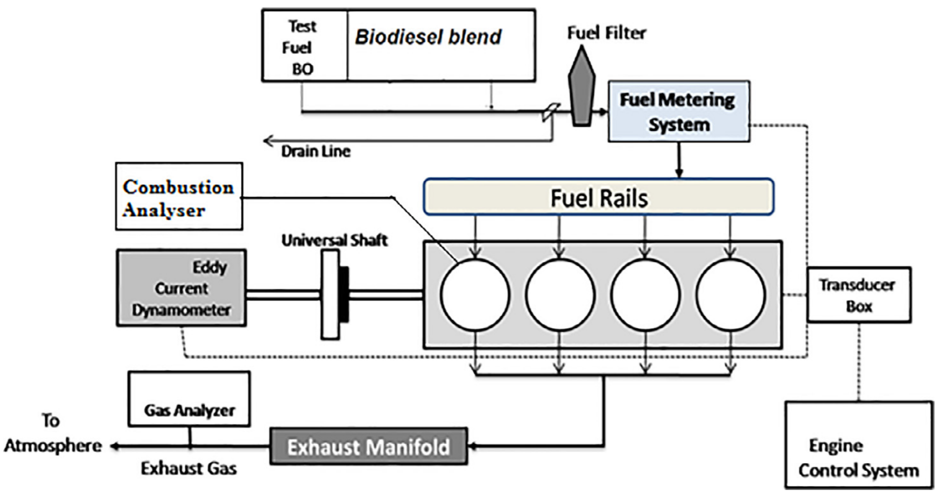

Fig. 1. A simple schematic of the engine test-bed.

conventional fuel to assess the effect on the performance and regulated emission of a diesel engine in this study.

2. Materials and methods

2.1. Materials

The alteration of the fuel has been conducted by mixing 20% of waste cooking oil biodiesel (WCB) with 80% diesel fuel. The biodiesel made from waste cooking oil was obtained from a colleague. In this study, only 20% biodiesel was selected based on the recommendation of the researchers that maximum of 20% biodiesel is allowed to a diesel engine without any modification. The characteristics of the used fuel is presented in Table 1.

2.2. Engine performance and emission setup

Performance and emission characteristics were carried out by a Kubota (model V3300) multi-cylinder diesel engine. A schematic diagram of the engine testbed is shown in Fig. 1 and the specification of the engine is represented in Table 2. Data for performance and emission analysis of the engine were collected at a variable speed ranging from 1200 rpm to 2400 rpm for every 200-rpm interval and full load condition. The emission of hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxides (NOx) were measured using a gas analyser (CODA 5, Australia). On the other hand, particulate matter (PM) was analysed by an MPM-4 M particulate metre. The engine was warmed up first with diesel fuel and later shifted to biodiesel blending for the test. Finally, the injection system and fuel line were cleaned by running the engine with diesel again.

Table 2
The engine specifications that were employed in this research.

Model	Kubota V3300
Type	Vertical, 4 cycles liquid-cooled diesel
No. of cylinder	4
Total displacement (L)	3.318
Bore × Stroke (mm)	98 × 110
Combustion system	E-TVCS
Intake system	Natural aspired
Output:	
Gross intermittent (kW/rpm)	54.5/2600
Net intermittent (Rated power output) (kW/rpm)	50.7/2600
Net continuous (kW/rpm)	44.1/2600
Rated Torque (N m/rpm)	230/1400
Compression ratio	22.6
No-load high idling speed (rpm)	2800
No-load low idling speed (rpm)	700–750
Direction of rotation	Counterclockwise (viewed from flywheel side)
Governing	Centrifugal fly high-speed weight governor
Starter capacity (V-kW)	12–2.5
Alternator capacity (V-A)	12–60

3. Results and discussion

3.1. Performance parameters

The performance of the WCB blend in a diesel engine was evaluated in terms of brake power (BP), brake specific fuel consumption (BSFC),

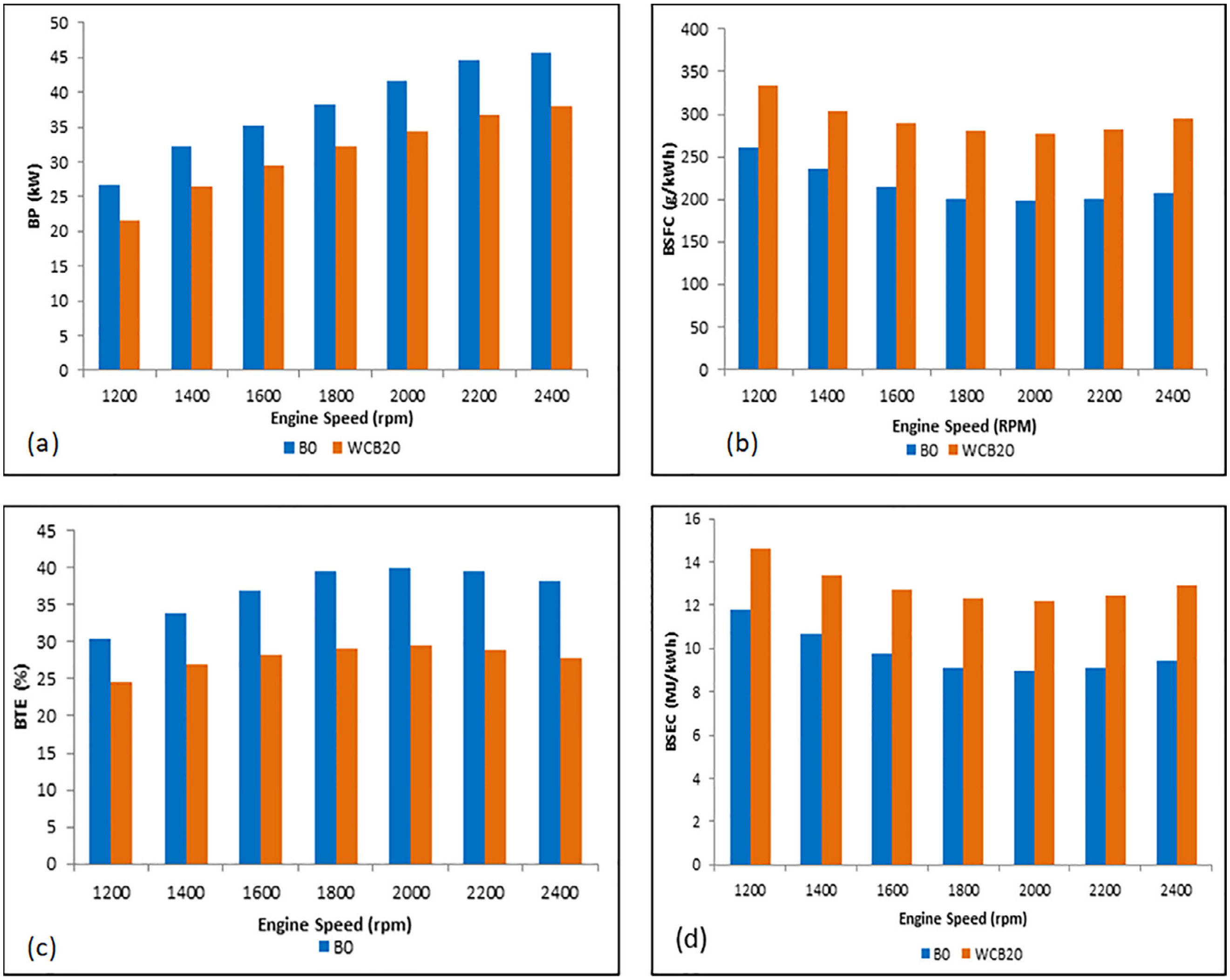

Fig. 2. Variation of BP, BSFC, BTE and BSEC in relation to the engine speeds (rpm) (a) BP with engine speed (b) BSFC with engine speed (c) BTE with engine speed (d) BSEC with engine speed.

braking specific energy consumption (BSEC), and braking thermal efficiency (BTE).

Brake power (BP) of conventional diesel and WCB20 has been compared with the change of engine speed in Fig. 2**a**. It is seen that the BP of diesel was higher than WCB20 in every condition since the conventional diesel had a higher calorific value and lower viscosity compared to WCB20. Furthermore, it is also noticed that BP increased with the increase of the speed of the engine. The maximum BP of WCB20 was 37.91 kW which was recorded at 2400 rpm. On average, the BP of WCB20 was 6.52% lower than the BP of diesel.

BSFC, a measure of the efficiency of fuel, is ascertained as the rate of fuel consumption in an engine with respect to its power. Fig. 2**b** represents the BSFC of commercial diesel and WCB20. It is noticed that the BSFC of biodiesel was higher than commercial diesel. This is because of the higher density, viscosity and lower heating value of biodiesel [15]. To produce the same amount of power, more biodiesels is consumed compared to conventional diesel oil. BSFC of diesel and WCB20 was declined with the increase of engine speed up to 2000 rpm. Furthermore, BSFC rose slightly with a further increase in engine speed. On average, the BSFC of WCB20 was 36.15% higher compared to the BSFC of diesel. A similar trend was found in Karthickeyan et al. [16] whose conducted the *Pistacia khinjuk* biodiesel in a diesel engine.

Fig. 2**c** shows brake thermal efficiency variation with speeds. BTE is inversely proportional to the BSFC. In this study, it was discovered that the BTEs of both diesel and biodiesel rise with rising engine speeds, with WCB20 having a lower BTE of 9.01% than diesel fuel. This is owing to the low heating value and higher BSFC of WCB20 biodiesel blended fuel.

Brake specific energy consumption (BSEC) is a measure of the required energy to generate one unit of power per hour and it is obtained by multiplying BSFC with the calorific value of the fuel. The change of BSEC with engine speed was shown in Fig. 2**d.** It is found that the BSEC of WCB20 was lower than the diesel. The reason for this phenomenon is heating value of WCB20 is less than diesel fuel. Moreover, BSEC of diesel and biodiesel decreased with increasing speed up to 2000 rpm but then start rising again at speed above that. This is because of the lower BTE of biodiesel fuels.

3.2. Emission parameters

In this study, engine emission was appraised in terms of particulate matter (PM), carbon dioxides (CO), hydrocarbon (HC) and nitrogen oxide (NOx).

PM is a tangled mixture of tiny particles and liquid droplets that form as a result of the combustion of fuel in an engine's combustion chamber. The fluctuation of PM emissions for both diesel and biodiesel blended fuel is depicted in Fig. 3a. The average PM concentrations for WCB20 and B0 fuel were 182 and 216 ppm, respectively. When com-

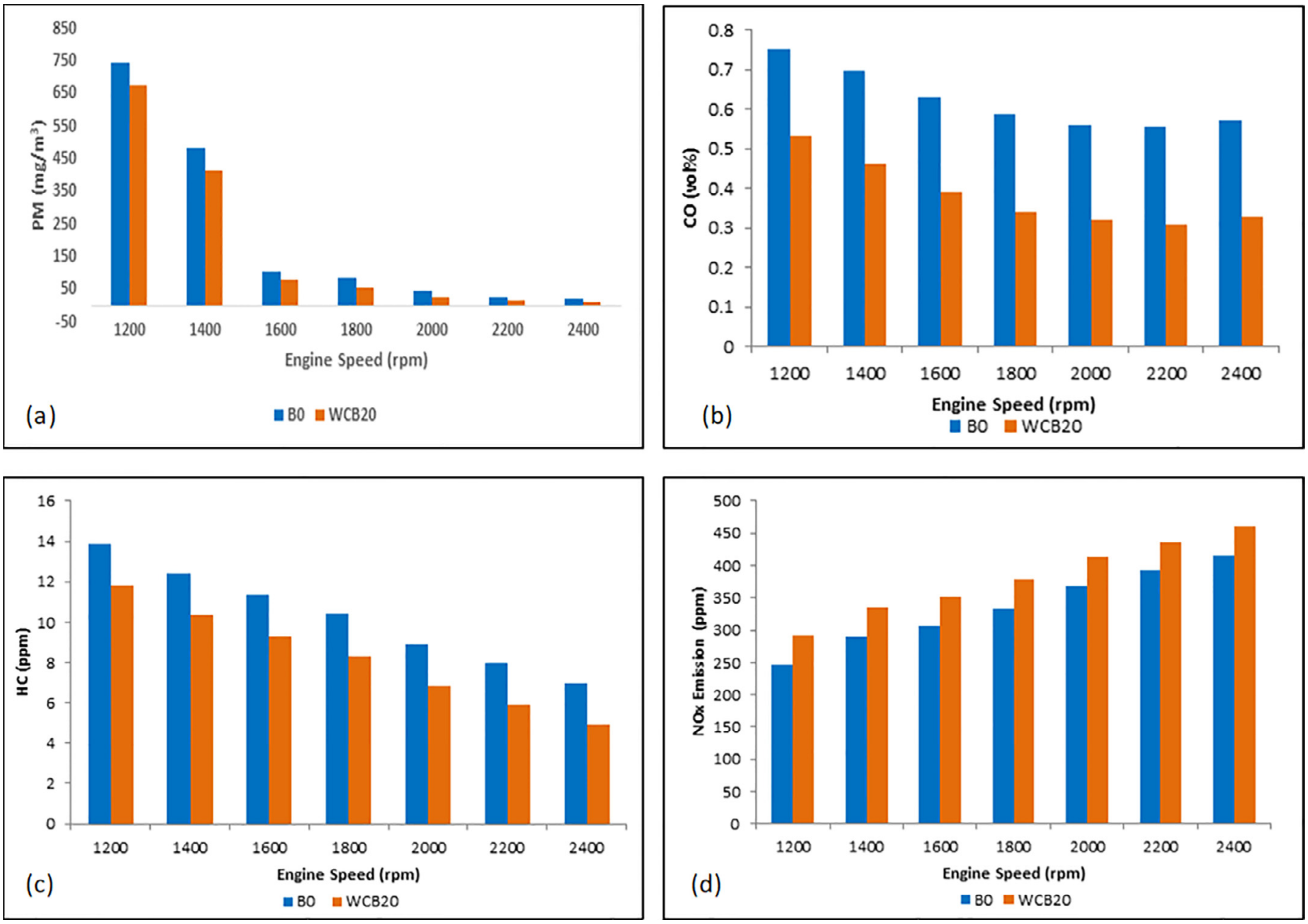

Fig. 3. (a) PM in relation to engine speed (b) rate of CO emission with engine speed (c) rate of HC with engine speed (d) NOx emission with engine speed.

paring the WCB20 fuels to the specified diesel fuel, it is noticed that PM concentrations are reduced by 15.50%.

CO emission is the output of unburned fuel due to the lack of presence of enough oxygen in the combustion zone. The rate of CO emission with engine speed is shown in Fig. 3b. The graph shows clearly that WCB20 released less CO fume in comparison to diesel fuel. This can be attributed to the fact that biodiesel contains oxygen in its molecular composition which plays a significant role in completing the combustion of the fuel. The maximum and minimum CO emission for WCB20 was observed at 1200 rpm and 2200 rpm, respectively. The average reduction of CO for WCB20 relative to conventional diesel was observed at 38.93%.

Unburned hydrocarbon emission is the consequence of the imperfect combustion of fuels and flame quenching. The calculated HC emission has been presented in Fig. 3c. It is noticed that the unburned HC emissions of WBC20 are less as compared to diesel. This is because of the higher oxygen content in biodiesel. Moreover, It is also observed that the HC discharge decreased with the increase of engine speed for both fuels. This can be attributed to the improved homogeneity of the mixture for proper atomization of fuel due to the higher flow rate at the inlet [17].

The variation of NOx emission in diesel and WCB20 has been presented in Fig. 3d. NOx emission for biodiesel is comparatively higher than conventional diesel. For WCB20, the NOx emission was 45 ppm which is 7.40% lower than the corresponding value of diesel fuel. Complete combustion and higher viscosity of WCB20 are the main reasons for higher NOx emission [18]. A similar trend is found in Karthickeyan et al. [19] study which claimed that higher NOx observe for B20 Blend. Oxygenated fuel (WCB20) leads to complete combustion that ultimately results in higher combustion temperature and NOx emission. Moreover, the viscous nature of biodiesel and its blend with diesel can cause poor atomization with a shorter ignition delay that also finds the way for higher NOx emission. Additionally, NOx emission for B0 and WCB20 increased gradually with the rise of engine speed.

4. Conclusions

This work deals with the influence of alteration of diesel fuel on engine performance and emission characteristics. It can be concluded that WCB20 offer inferior BP and BTE which are 6.52% and 9.01% lower than diesel fuel. In addition, BSFC and BSEC of WCB20 were 36.15% and 32.16% which are larger than diesel fuel. This is due to the higher density and viscosity and the lower energy content of the biodiesel blends. On the other hand, WCB20 is able to reduce the PM, HC and CO emission significantly but slightly increases the NOx emission. These results were ascribed to the higher cetane numbers and oxygen contents of the biodiesel blended fuels. In summary, a lower cost feedstock i.e., waste cooking oil can be a promising alternative to fossil fuel to reduce the harmful emission. Thus, alteration of 20% diesel by waste cooking oil biodiesel blend is recommended to be utilised in current diesel engine vehicle which able to reduce the harmful emission.

Declaration of Competing Interest

All authors declare that there is no conflict of interest and all the elements of the submission are also in compliance with the journal publishing ethics. By submitting this revised manuscript, the authors agreed that the copyright for their article should be transferred to this journal if the article is accepted for publication. The work contained within the research paper is our original contribution and has not been published anywhere.

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