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FUEL PROPERTIES AND EMISSION CHARACTERISTICS OF BIODIESEL FUEL PRODUCED FROM WASTE COOKING OIL USING CaO/CaFe$_2$O$_4$ CATALYST

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Abstract
This study investigates the fuel properties and emission characteristics of biodiesel derived from waste cooking oil (WCO) feedstock utilizing a novel CaO/CaFe$_2$O$_4$ composite catalyst. The biodiesel production process involves transesterification, yielding a renewable and environmentally friendly fuel source. Fuel properties such as density, kinematic viscosity, flash point, cetane number, and calorific value of the produced biodiesel and its blends were determined and compared with the ASTM biodiesel standard. The chemical composition of the fatty acid methyl ester of the produced biodiesel was confirmed with a Gas Chromatography-Mass Spectrometer and a Fourier Transformed Infrared Spectrometer was used to determine the functional groups and chemical bonds present in the biodiesel. The characteristics of the exhaust emissions of the different blends of biodiesel with petro-diesel (B20, B50, and B80) as well as pure biodiesel (B100) and petro-diesel (D100) were evaluated through the exhaust gas emissions analysis at a constant speed of 1500 rpm in a four-stroke diesel engine. Exhaust gas emissions such as carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO$_2$), nitrogen oxides (NO$_X$), were measured. The results indicate that the WCO produced biodiesel meets the ASTM standard specifications for these properties, showcasing its potential as a feasible alternative to petrodiesel. Additionally, emission study results indicate that utilizing B20, B50, and B80 blends resulted in reduced CO, HC, and CO$_2$ emissions when compared to petro-diesel fuel amounting to (7.88, 25.29, and 31.26%), (9.24, 5.54, and 27.85%) and (10.04, 6.02, and 21.96%) respectively. All biodiesels (blend or raw) emit more NO$_X$ than petro-diesel.

Introduction

The utilization of fossil fuels as the primary source of energy has played a vital role in the progress of the society (Pandey, 2021), but it has also given rise to significant environmental and health issues. The combustion of fossil fuels releases harmful pollutants, including carbon monoxide, sulfur oxides, nitrogen oxides, unburned hydrocarbons, and particulate matter, which are pollutants of health concerns responsible for various degrees of health problems like cancer, birth defects, and respiratory problems (Khan et al., 2020). In addition, carbon dioxide (CO_2) a greenhouse gas (GHG) which leads to climate change, acid rain, and ocean acidification is mostly released during fossil fuel combustion ((Chhetri et al., 2008). To address these challenges, it is imperative to explore and harness renewable energy sources such as biofuels, solar power, hydroelectricity, geothermal energy, and wind power (Pandey, 2021).

Among the various biofuels available, biodiesel emerges as a promising alternative to fossil fuels due to its similar chemical and physical properties, non-toxic nature, high oxygen content, and environmental friendliness (Verma and Sharma, 2015). Biodiesel offers several advantages over conventional diesel fuel, including its biodegradability, enhanced combustion efficiency, higher cetane number (CN), and lower sulfur content. The production of biodiesel involves a reaction between triglyceride and alcohol using an appropriate catalyst through a process known as transesterification (Suzihaque et al., 2022). Different vegetable oils, ranging from castor oil, soybean oil, jatropha seed oil, cottonseed oil, waste cooking oil, oils from wood, oleaginous microorganisms, to algae, can be utilized for biodiesel production. The utilization of waste cooking oil for biodiesel production is particularly advantageous as it not only recycles used oil but also reduces pollution, provides a solution for waste management (Degfie et al., 2019), and contributes to environmental preservation and economic sustainability.

Biodiesel can be utilized as a standalone fuel or blended with diesel fuel in diesel engines (Rajasekar et al., 2020). Studies have shown that diesel engines running on biodiesel emit lower levels of carbon monoxide and hydrocarbons compared to traditional diesel (El-Baza et al., 2016). Moreover, due to its lower carbon-to-hydrogen ratio (Joy et al., 2019), biodiesel emits less carbon dioxide when completely burned, thereby improving the overall environmental quality (Ogunkunle and Ahmed, 2021). However, there are conflicting findings regarding the impact of biodiesel on carbon dioxide emissions, with some studies suggesting that more efficient combustion leads to increased emissions (Gharehghani et al., 2017). Characteristics of biodiesel, such as its higher cetane number, absence of aromatics, oxygen content, and low sulfur content, contribute to lower emissions of carbon monoxide, particulate matter, and hydrocarbons in exhaust gases. However, the emissions of nitrogen oxides tend to increase (Karmakar et al., 2018). Despite these positive effects, biodiesel has certain limitations, including higher viscosity, density, and lower calorific value, which restrict its complete substitution for diesel fuel.

Researchers have conducted investigations into various blends of biodiesel and diesel to assess their feasibility as fuels for existing diesel engines. The properties of fuel and emission characteristics for different biodiesel blends, including those derived from algae (El-Baza et al., 2016; Tizvir et al., 2022), coconut acid oil (Rajasekar et al., 2020) and waste frying oil (Kathirvelu et al., 2017; Yusuff et al., 2017) have been studied. The findings indicate that biodiesel blends containing 20 percent biodiesel can enhance engine performance by 0.93% (Rajasekar et al., 2020) and reduce emissions of carbon monoxide by 15% (El-Baza et al., 2016), hydrocarbons by 18.28% (Tizvir et al., 2022)), carbon dioxide 1.34% ((Karmakar et al., 2018). However, In the study by Gokalp et al, observed that nitrogen oxides (NO_X) emissions increased by 4.5%, 10%, and 15.5% for B20, B50, and 100% pure biodiesel, respectively (Gokalp et al., 2011).

The current study aims to explore the properties of fatty acid methyl ester (FAME) obtained from waste cooking oil using a $CaO/CaFe_2O_4$ nanocatalyst. Additionally, it seeks to investigate the emission characteristics of biodiesel blends as a substitute for diesel fuel in compression ignition engines. By examining the properties and emissions of biodiesel blends, the study intends to contribute to a deeper understanding of the potential of biodiesel as a sustainable and environmentally friendly fuel option.

Materials and Methods

Materials

For the synthesis of $CaO/CaFe_2O_4$ composite nanocatalyst, nitrate ($Ca(NO_3)_2 \cdot 4H_2O$; Loba Chemie PVT LTD, 98%), Iron (III) nitrate nonahydrate ($Fe(NO_3)_3.9H_2O$; CDH, 98%), citric acid ($C_6H_7O_7OH$; Finkem, 99.8%), ethylene glycol VWR, 99.9%), calcium oxide CaO; Loba Chemie PVT LTD, and deionized water were used for this experimentation without more purification. The WCO was collected from a local eatery on the Kwame Nkrumah University of Science and Technology campus in Kumasi, Ghana. After purifying the WCO collected, it was characterized based on its physicochemical properties. Methanol (CH_3OH; VWR, 100%) was used as a transesterification reactant to produce biodiesel. The fatty acid methyl esters present were identified utilizing Gas chromatography-mass spectrometry (GC-MS).

Synthesis of calcium oxide calcium ferrite CaO/ $CaFe_2O_4$ composite nanocatalyst

Synthesis of calcium iron oxide nanoparticles ($CaFe_2O_4$) was carried out using the combustion technique, calcium nitrate $Ca(NO_3)_2.4H_2O$ and ferric nitrate $Fe(NO_3)_3.9H_2O$ mixture in a molar ratio of 1:2 M was dissolved in 70 mL of distilled water (Sulaiman et al., 2018). After mixing the solution, citric acid (1.5–2 times of stoichiometric ratio) was used as a chelant. The solution mixture was stirred with a magnetic stirrer for 60 mins and it was heated at 100°C to evaporate the excess water and to form a viscose gel. Thereafter, about 6 mL of ethylene glycol was added and the viscose gel was calcined at 550°C for 2 h in a furnace. The resulting sample was slightly crushed with a mortar and pestle to obtain the calcium ferrite nanoparticles in powder form (Yunas et al., 2018). The second step of the synthesis involved loading of (15-30%wt) CaO on the $CaFe_2O_4$. The CaO and magnetic $CaFe_2O_4$ were mixed and ground for 15 min. The mixture was then sonicated in an ultrasonic bath for 60 min in the presence of about 50 ml of ethanol (Firouzjaee and Taghizadeh, 2017). Ethanol was removed by evaporation at 78°C. The resulting catalyst was dried for 12 hrs at 110°C and calcined for 4 hrs at 550°C.

Biodiesel production from waste cooking oil

The transesterification reaction of WCO using magnetic CaO/ $CaFe_2O_4$ nanocatalyst was performed in a 250 mL round-bottom flask having three-necked with a water-cooled condenser, thermocouple, and magnetic stirrer. The optimum reaction conditions of 4 wt% catalyst loading, temperature of reaction at 70°C, methanol-to-oil molar ratio of 12:1, 2hr reaction time from our previous study were used to produce biodiesel (AbdulRasheed et al., 2023). The catalyst was dispersed in methanol at 40°C at a stirring speed of 600 rpm for 30 minutes. The oil was then added to the reaction mixture. A permanent magnet was used to separate the catalyst from the reaction mixture once the reaction was completed. The resultant product was rinsed three times with warm distilled water to get pure biodiesel and thereafter it was heated to evaporate residual methanol before being allowed to settle in a separating funnel (Firouzjaee and Taghizadeh, 2017). The quality of the biodiesel was assessed by analyzing its fuel characteristics, such as kinematic viscosity, cetane number, calorific value, density, and flash point, according to international standards (ASTM D 6751) (Borah et al., 2019; El-Baza et al., 2016)

$$\%Yield\ of\ biodiesel = \frac{weight\ of\ bidiesel\ produced}{weight\ of\ oil\ used} 100 \quad (1)$$

Preparation of the various fuel blends

WCO biodiesel fuel blend samples were produced using mechanical mixing and blending (based on volume). Three blends B20, B50, and B80 containing 20%, 50%, and 80% biodiesel respectively were made by mixing a measured volume of the biodiesel produced with a given volume of petro-diesel acquired from Nigerian National Petroleum Corporation (NNPC) fuelling station in Nigeria. Sample four contains 100% biodiesel identified as B100 and the fifth is petro-diesel (D100). The various blends as well as B100 and D100 were agitated with the aid of an electrical magnetic stirrer at a constant stirring rate of 400 rpm for 30 minutes to attain equilibrium at room temperature before subjecting it to test in a diesel engine (Jalaludin et al., 2020; Yusuff et al., 2017). Furthermore, the physicochemical properties of the biodiesel such as the kinematic viscosity, density, flash point, calorific value, and cetane number, were measured and compared with that of the ASTM standard..

Engine setup and specification

The test engine employed in this investigation is a single-cylinder horizontal, water-cool, four-stroke diesel engine made by Jintian. The engine specifications are shown in Table 1. The engine remained at a constant speed of 1500rpm for the operation condition of the engine. Prior to the test, the engine is run on diesel fuel for around ten minutes; then, the fuel was changed for the subsequent test to confirm there were no traces of the preceding fuel in the system, ensuring consistency and accuracy of measurement results. Measurements of CO, HC, CO_2, and NO_X exhaust emission concentrations were made using syngas analyzer gas board-3100P, and concentrations of emissions from the exhaust, including, CO, CO_2, O_2, NO_X, and HC, were recorded.

Table 1. Details of the diesel engine used to test the WCO-derived biodiesel emission characteristics.

Maker	Jintian
Model	R170A
Type	Single cylinder, horizontal, 4-stroke
Bore x stroke(mm)	70 x 70
Displacement (L)	0.231
Rated power (kW/hp)	2.94/4
Rated speed (rpm)	2600
Combustion system	Swirl combustion chamber
Cooling method	Water cool
Lubrication method	Combined pressure and splashing
Start method	Hand cracking

Biodiesel emission characteristics

The diesel engine was fuelled with the produced WCO biodiesel blended with petro-diesel, pure biodiesel, and petrol diesel respectively. Thereafter, the ignition engine having the technical feature presented in Table 2, was started by hand cracking. The diesel engine was allowed to stabilize after running for nearly 30 minutes. The analysis of exhaust emission was carried out using a portable infrared syngas analyzer gas board-3100P. A gas sampling probe connected to the analyzer was used to collect the combustion gases after ignition. Then, the concentration of CO_2, O_2, CO, CH_4, and NO_2 in the combustion gases were measured by the gas analyzer

Results and Discussion

Results

Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The chemical composition of fatty acid methyl esters that made up the biodiesel produced was analyzed using GC-MS. The different fatty acid methyl esters profiles for the produced biodiesel are shown in Figure 1.

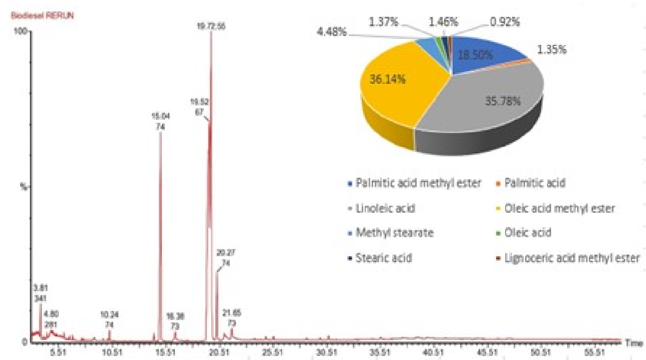

Figure 1. The GC-MS Chromatogram of WCO-derived biodiesel

Table 3, displays the composition of the fatty acid of the WCO-derived biodiesel, and the results from total ion chromatography were used to determine the relative percentage of fatty acid methyl esters present. The result showed that the chain length ranged from C16 to C24. In FAME analysis, the "n" in Cn refers to the number of carbon atoms in the chain of fatty acids, while the "m" indicates the number of double bonds. The main fatty acids in the produced WCO biodiesel include oleic acid methyl ester (C18:1, 36.13%), linoleic acid (C18:2, 35.78%), followed by palmitic acid methyl ester (C16:0, 18.49%). Methyl stearate (C18:0, 4.48%), stearic acid (C18:0, 1.46%) oleic acid (C18:1), palmitic acid (C16:0, 1.37%), and Lignoceric acid methyl ester (C24:0, 0.92%) with a major contribution by oleic acid. Meanwhile, the percentages of saturated and unsaturated fatty acids were discovered to be 26.73% and 73.28%, respectively. The findings are consistent with the profile of the waste cooking oil reported in the literature by (Issariyakul et al., 2007; Mohan et al., 2014; NguyenThi et al., 2018) which listed oleic acid as the major fatty acid in biodiesel synthesized from heated sunflower oil with 37.59 wt%. Therefore, it is obvious from this fatty acid composition profile that waste cooking oil is ideal for making biodiesel since the FAME analysis revealed that the main fatty acids in these biodiesels were oleic acid, linoleic acid followed by palmitic acid. Additionally, these components (C18:1, C16:0.) can enhance key fuel properties such as kinematic viscosity, cetane number, the heat of combustion, and oxidative stability as well as increase fuel efficiency.

Fourier Transform Infrared Spectroscopy Analysis

The FTIR spectra in Figure 2, reveal details about the functional groups and chemical bonds that are present in the biodiesel produced. The chemical bonds in the sample have distinct vibrations, which are represented by each peak in the FTIR spectrum. Thus, the functional groups and chemical bonds present in the sample were determined by analyzing the positions and intensities of the peak.

The ester bonds in the FAME are indicated by distinctive

Table 2. Chemical composition of WCO derived Biodiesel

S/N	Component name	The common name of the fatty acid source	Cn:m	Retention time	Area%
1	Hexadecanoic acid, methyl ester	Palmitic acid methyl ester	C16:1	15.045	18.50
2	n- Hexadecanoic acid	Palmitic acid	C16:0	16.383	1.35
3	9,12-octadecadienoic acid(Z,Z) methyl ester	Linoleic acid	C18:2	19.518	35.78
4	9-Octadecenoic acid (Z)- methyl ester	Oleic acid methyl ester	C18:1	19.72	36.14
5	Octadecanoic acid, methyl ester	Methyl stearate	C18:0	20.27	4.48
6	9-Octadecenoic acid (Z)	Oleic acid	C18:1	20.907	1.37
7	Octadecanoic acid	Stearic acid	C18:0	21.645	1.46
8	Tetracosanoic acid methyl ester	Lignoceric acid methyl ester	C24:0	35.525	0.92

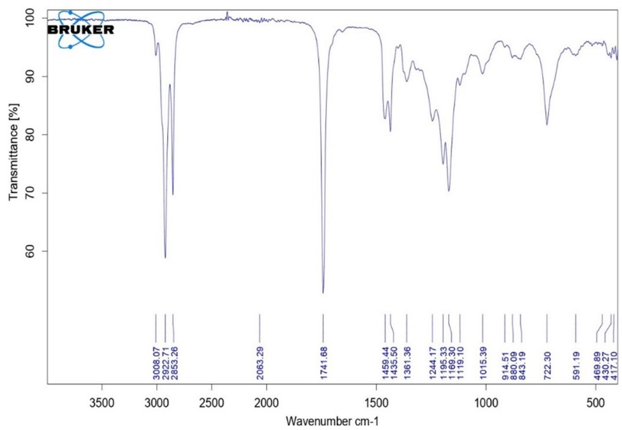

Figure 2. FTIR Spectra of WCO-derived biodiesel

Table 3. Chemical composition of WCO derived Biodiesel

FTIR (bands position, cm^{-1})		Type and origin of vibrations
WCO derived biodiesel	Heated sunflower oil methyl esters as reported by Matwijczuk et al. (2017)	
-	3352	(O-H) in H2O stretching vibration
3008.07	3010	(C-H) stretching vibration
2922.71	2930	(CH2, CH3) symmetric and asymmetric stretching
2853.26	2861	
1741.68	1742/1713	C =O group of esters
-	1658	(C=C) stretching vibration
1459.44	1461	-C-H (in CH2) bending
1435.56	1435	=C-H(Cis) bending
-	1418	
-	1403	(=C-H (cis-)) stretching vibration
1361.36	1377	-C-H symmetric stretching and (CH3) bending
-	1365	-C-H strong, (CH3) bending
-	1318	(CH) deformation vibration
-	1276	(CH2) deformation vibration
1244.17	1246	-C-O stretching or -O-CH2-C
1169.30	1170	
-	1194	C-O
1119.10	1117	(C-C) stretching vibration
-	1130	(C-C)
914.51	915	-OH
880.09	859	(C-O-C) stretching vibration
843.19	840	(C-O-C) symmetric stretching vibration or (C-C) stretching vibration
722.30	722	-

peaks in the FTIR spectrum. There may be additional peaks as well, such as those associated with residual alcohol, impurities, and water. The main absorption bands are interpreted in Table 4.

The most acceptable band for the detection and quantification of FAME in medium petroleum fractions was found to be between 1,750-1,740 cm^{-1} wavelength. FAME exhibits very strong absorption in the C=O carbonyl group band (1,700-1,800 cm^{-1}) while hydrocarbon fractions have low or no absorption in this region. Esters exhibit distinctive, strong absorption bands produced by valence vibrations of the C-O and C=O atoms. Therefore, the carbonyl functional group stretching vibration of the C=O group of esters, which is responsible for the greatest distinctive peak in the spectrum at 1741.68 cm^{-1} was identified in the WCO-derived biodiesel. Hence, the existence of these functional groups demonstrates that the synthesized biodiesel was of good quality, and this finding is consistent with the report by Matwijczuk et al. (2017)

Biodiesel properties

The quality of biodiesel produced is determined by analyzing the fuel characteristics (Linganiso et al., 2022). The property of biodiesel is an indication of whether it is suitable for the engine's performance and emissions. Biodiesel must meet international biodiesel standard requirements in terms of characteristics and attributes. These requirements consider the American Society for Testing and Materials (ASTM 6751-3). Table 4, presents the physical and chemical properties including cetane number, kinematic viscosity, density, calorific values, and flash point of various biodiesel blends that were blended with the same petro-diesel and compared to those of the ASTM standards.

Fuel density has a major influence on fuel performance because of the close relationship between density and some engine factors such as cetane number, heating value, and viscosity. The lower the density, the easier its atomization and better complete combustion. Hence, fuel density also affects its atomization and combustion, (Barabás and Todoruţ, 2011). According to Table 4. The pure biodiesel (B100) and the various blends have density values between 857.10 to 873.80 kg/ m^3. Because the densities of B50, B80, and B100 blends

Table 4. Physical and chemical properties of WCO biodiesel and its blend compared to biodiesel ASTM standards

Fuel properties (Avg.)	B20	Error % at 95% C.L	B50	Error % at 95% C.L	B80	Error % at 95% C.L	B100	Error % at 95% C.L	ASTM standards Min.	ASTM standards Max.
Density at 15°C, kg/m^3	857.1	0.021	860.8	0.005	865.0	0.245	873.8	0.0107	860	890
Kinematic viscosity at 40°C, mm^2/s	2.85	0.4863	2.89	0.4863	2.97	0.842	3.63	0.4863	1.9	6
Flash point°C	125	0.7699	90	0.7699	121	0.7699	132	0.7699	120	-
Cetane number	57.74	0.0341	51	0.1966	54.43	0.0196	58	0.4539	47	-
Calorific value MJ/kg	42.57	0.0457	39.75	0.0403	39.25	0.0698	37.152	0.0015	35	-

meet the ASTM criteria. It implies that based on their density characteristics, B50, B80, and B100 are of good quality than B20 which has its density below the ASTM standard density value. The densities of the pure biodiesel and blends B50, and B80 are more than that of B20 because of the molecular structure and weight of the pure biodiesel (Joy et al., 2019).

Kinematic viscosity is one of the essential properties of fuel since it affects combustion, atomization, and fuel injection characteristics (Reham et al., 2015). As shown from the obtained result in Table 4. The kinematic viscosities of the blends range from 2.85 - 3.63 mm^2/s and this falls within the ASTM limit. In contrast to the pure biodiesel, the kinematic viscosities of the different blends were lower than that of the biodiesel produced which means that blending leads to a decrease in the viscosity (Yusuff et al., 2019). However, due to ineffective atomization, more viscous fuel is usually undesirable for use in diesel engines (El-Baza et al., 2016). Hence, fuel with lower viscosity indicates improved atomization, total combustion, and reduced emissions of unburned hydrocarbons and smoke. Biodiesel has a higher viscosity because it is more polar due to the presence of electronegative oxygen.

The cetane number CN is a chemical property of fuel that influences the ignition delay of compression ignition engine CI. The cetane number of the pure biodiesel (B100) produced from this study is 58 and is larger than the cetane number of the various blends B20, B50, and B80 which were 57.74, 51, and 54.43 respectively. However, all the blends have their cetane number higher than the minimum requirement of ASTM standards and as a result, it is anticipated that fuel quality and combustion efficiency will be better than that of diesel fuel. Fuel with higher CN typically has shorter ignition delays and ignites quickly (Hasan and Rahman, 2017) thereby resulting in improved power output, reduced emissions, and increased fuel efficiency. Thus, these blends have a good cetane number which can enhance engine performance.

The flash point is a crucial factor that has an impact on fuel handling, transportation, and storage. Fuels are categorized for distribution, storage, and transportation based on their flash point (Barabás and Todoruţ, 2011). As observed from Table 4, the flash point of B20, B50, B80, and B100 were 125, 90, 121, and 132°C respectively. Owing to the dilution effect of diesel fuel B20 has a higher flash point than B50 and B80. Meanwhile, the flash point of B100 is higher than the flash point of B20 because it contains more oxygen than petroleum-based diesel fuel, which makes it less volatile and harder to ignite. Higher flash point lessens the risk of an unanticipated fire hazard (Karmakar et al., 2018), indicating that B100 is safe in both transportation and storage.

Fuel calorific value measures the heat released into the combustion chamber during combustion and it reveals the amount of energy that is readily available from that fuel. It is an important factor in fuel selection because, a fuel that has a higher calorific value has more energy in it (Oliveira and Da Silva, 2013). Hence, it was observed in Table 4, that the heating values of B20 were higher than that of other blends B50, B80, and B100 and this indicates that B20 releases the most energy when combusted. Generally, biodiesel contains more oxygen and has lower carbon to hydrogen ratio than diesel, and hence has a lower heating value. Therefore, the blends containing larger percentages of biodiesel have lower calorific values and lower energy density. Nonetheless, the heating values of the various biodiesel blends (42.21-37.15 MJ/kg) were within the allowable limits for biodiesel fuel.

According to some researchers (Hasan and Rahman, 2017), B20 improves engine performance because its density, viscosity, flash point, as well as a calorific value, was close to diesel, all of which increased engine performance. Hence, this might be the reason for the observed different trend in some of the properties of B20 blends such as the density.

Characteristics of emission of WCO-derived biodiesel-blends and diesel

The exhaust gas emissions for various blends of biodiesels B20, B50, B80, pure biodiesel (B100), and diesel are compared at an engine speed of 1500 rpm. The gases whose emissions were determined by the gas analyzer include carbon monoxide (CO), unburnt hydrocarbon, (UHC), oxygen (O_2), Carbon dioxide (CO_2), and oxides of nitrogen (NO_X).

Carbon (II) oxide emission (CO)

The CO emissions of the blends B20, B50, B80, B100, and D100 are presented in Figure 3. It was found that the CO emission for the different blends of biodiesel was lower than that of diesel fuel, and the CO emission was reduced further as the ratio of biodiesel in the blends increased. When compared with the petro-diesel, the decreased CO emission obtained from B20, B50, B80, and B100 was 7.88%, 9.24%, 10.62%, and 13.04% respectively, Biodiesel properties like enhanced CN and oxygen content are responsible for the reduced level of CO emission in biodiesel-blend compared to diesel fuel. Comparing WCO biodiesel blends to diesel fuel, the oxygen molecules in biodiesel improved vaporization and atomization. This result is consistence with the findings of (El-Baza et al., 2016; Hasan and Rahman, 2017)

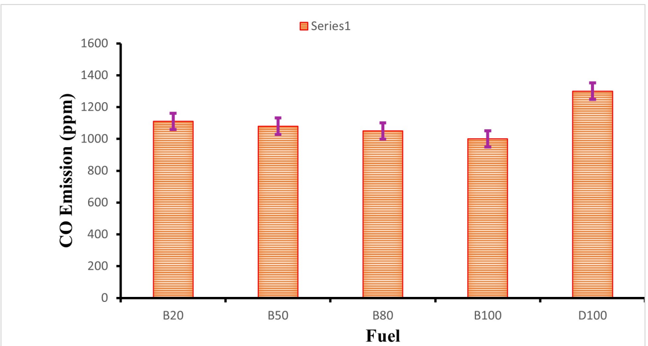

Figure 3. Carbon (II) oxide emission of different blend

Unburnt Hydrocarbon (UHC) emission

Due to incomplete fuel combustion in the engine, unburned hydrocarbons are released. Because biodiesel has built-in oxygen, which promotes better combustion (Gharehghani et al., 2017; Jalaludin et al., 2020), the HC emission from its combustion is lower than that from petro-diesel. WCO-derived biodiesel produced less HC emissions than diesel in this instance as well. As shown in Figure 4, the HC emission by petro-diesel decreases from 590 ppm to 352, 528, 523, and 512 ppm for B20, B50, B80, and B100 respectively. This is because an increased proportion of biodiesel in the blends reduces the ignition delay and as well promotes the reaction timing of the blends (Hasan and Rahman, 2017). The findings are in line with those in these references (El-Baza et al., 2016; Hannah et al., 2020; Karmakar et al., 2018; Rajasekar et al., 2020).

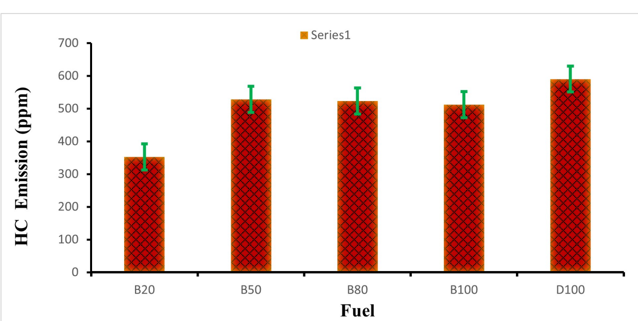

Figure 4. UHC emission of different blends

Oxygen O_2 emission

Figure 5 depicts the oxygen concentrations in the exhaust gases of the diesel engine for the fuels under investigation, the concentration of oxygen is higher when blended fuels were used than when petrol-diesel was used. The produced biodiesel in this study, (B100) has about 11.0% more oxygen than the petro-diesel while the percentages of the blends B20, B50, and B80 are 9.9% 9.6%, and 9.7% respectively more than that of the diesel. Higher oxygen-content fuels burn more effectively because some of the oxygen needed for combustion is already present. This implies that they can burn more completely since they need less oxygen from the surrounding air to burn completely. Thus, the oxygen content in these biodiesel blends is significantly large resulting in both more efficient combustion of the fuel and a greater oxygen level in the exhaust gas.

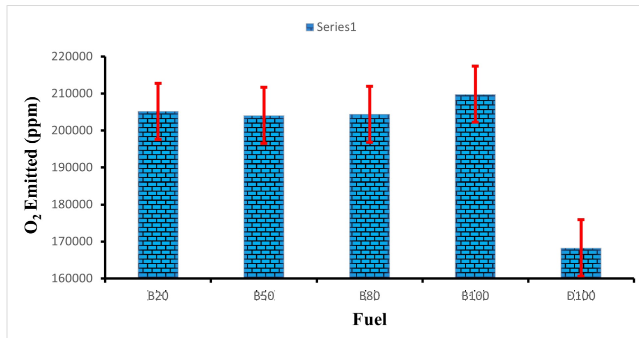

Figure 5. Oxygen emission of different blends

Carbon (IV) oxide emission (CO_2)

As observed from Figure 6, blends B20, B50, B80, and B100 in comparison to petrol-diesel fuel, produce fewer CO_2 emissions during complete combustion than the petro-diesel due to its lower carbon-to-hydrogen ratio (Hosseini et al., 2010; Utlu and Koçak, 2008). The trend of CO_2 emissions observed in this study is consistent with prior studies by these references (El-Baza et al., 2016; Karmakar et al., 2018).

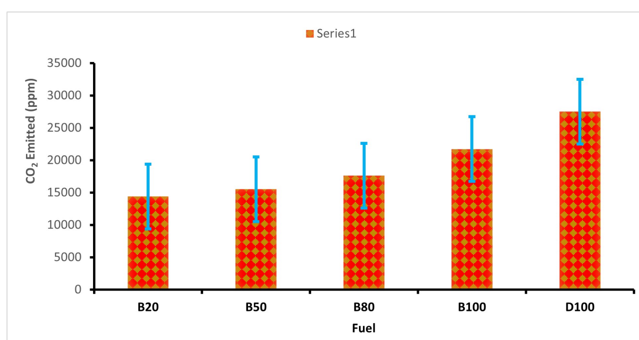

Figure 6. Carbon (IV) oxide emission of different blends

Nitrogen Oxide (NO_X) emission

Figure 7 compares the NO_X emissions of WCO biodiesel blends with petro-diesel fuel. It was found that the emission of

NO_X from the combustion of the various biodiesel blends B20, B50, B80, and B100 was higher than diesel and this findings is in agreement with the work of (Lahane and Subramanian, 2015; Rajasekar et al., 2020). Meanwhile, the blend with about 20%, B20 produce fewer NO_X emission compared to other blends. The increase in NO_X emission observed could be a result of the in-built oxygen present in the biodiesel which increases the amount of oxygen molecules in the engine cylinder during biodiesel combustion (Gharehghani et al., 2017; Jalaludin et al., 2020; Yang et al., 2012).

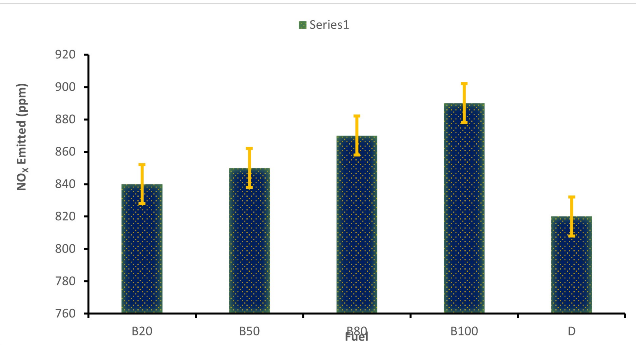

Figure 7. NO_X emission of different blends

Conclusion

In this research, the transesterification reaction of WCO was performed for the production of biodiesel. The fuel properties and the emissions characteristics of a diesel engine running on WCO-derived biodiesel blended with petro-diesel were studied and the main findings from this investigation indicate that the properties of the produced WCO biodiesel and the majority of its blends align with biodiesel ASTreduction, clean energy production, and addressing climate change concerns. Biodiesel blends derived from WCO, which exhibit decreased emission characteristics, demonstrate their potential as effective alternatives to pure diesel fM standards. An exception is noted with B20, where the density falls below the prescribed limit. Furthermore, the research shows that combustion of the various biodiesel blends and pure WCO biodiesel leads to higher NO_X emissions compared to petro-diesel. However, these biodiesel blends show reduced emissions of other gases, including CO, CO_2, and unburnt hydrocarbons, in comparison to petro-diesel when used in the diesel engine. Hence, the utilization of WCO as a biodiesel feedstock emerges as an economically feasible and sustainable solution for waste fuel.

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Conflicts of Interest

The authors declare there are no conflicts of interest.

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