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Performance and Emission Characteristics of Diesel Engine Fuelled with Waste Frying Oil Derived Biodiesel-Petroleum Diesel Blend

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Abstract. Direct use of vegetable oil as a fuel on compression ignition engine has been described as impossible, because of its high viscosity and density. Transesterification process and other methods have been identified as ways of reducing these two properties. The high cost of virgin vegetable oils and its competition for food have made the biodiesel unable to compete with fossil diesel and also hike its cost. In order to solve these menaces, in this study, waste frying oil was used as a feedstock for production of biodiesel via transesterification using anthill-eggshell promoted Ni-Co mixed oxides (NiCoAE) as heterogeneous catalyst. The composite catalyst was prepared via incipient wetness impregnation (IWI) method and thermally treated at 1000 ^{o}C for 4 h. The developed catalyst was characterized using FTIR and SEM techniques. The biodiesel produced under the favourable reaction conditions was blended with petroleum diesel in three different proportions (B20, B50 and B80) and were tested on diesel engine to evaluate their performance and emission characteristics. The blended fuel containing 20% by volume biodiesel (B20) emitted lowest percentage of CO and CO_2. The result obtained herein indicates that the mixture of biodiesel and petroleum diesel containing 20% biodiesel (B20) emitted less carbon monoxide (CO) and carbon dioxide (CO_2), thus, indicating best dual fuel combination, which can be used in diesel engines without any adjustment or modification in the engines. This result is in agreement with the findings reported in the literature and Energy Policy Act (EPA) of 1992.

Nomenclature

ASTM	American Society for Testing and Materials
B20	Blended fuel containing 20% biodiesel
B50	Blended fuel containing 50% biodiesel
B80	Blended fuel containing 80% biodiesel
CO	Carbon monoxide
Co	Cobalt
CO_2	Carbon dioxide
EN	European Standards
FTIR	Fourier Transform Infrared Spectrometry
GC-MS	Gas chromatograph mass spectrometer
Ni	Nickel
NICOAE	Anthill-eggshell promoted Ni-Co mixed oxides catalyst
NNPC	Nigerian National Petroleum Corporation
SEM	Scanning Electron Microscope
WFO	Waste frying oil

Introduction

Biodiesel, mixture of fatty acid alkyl esters, is a biogenic and oxygenated fuel which has a great potential in solving problems associated with mineral diesel. The use of substantial amount of mineral diesel to power compression ignition engine and the associated effects of green gas emissions and other environmental issues arising as a result of burning of convectional fossil fuels are the main problems confronting the entire globe nowadays [1]. Meanwhile, biodiesel as a renewable fuel is now being used to run diesel engine without making changes to engine components. However, the problems related to inter alia injector coking always occur in long run utilization of biomass derived fuel, so, biodiesel is usually blended with petroleum diesel without necessarily changing fuel consumption and engine performance [2]. Being a renewable fuel, carbons contained in biodiesel are biogenic which makes it to be contributing less to carbon cycle and when mixed with proportion amount of petroleum diesel, the emissions of SO_x and NO_x compounds are reduced. More so, biodiesel improves the qualities of diesel fuels [3].

In most countries, standard specifications for biodiesel has been put in place, for instance, ASTM D6751 and EN 14212 are being used in America and Europe respectively as biodiesel standard specifications, because European biodiesel standard is somehow stricter than American standard, EN 14212 is now being used by most countries [4]. In general, a code comprising a number indicating the content of biodiesel in percentage is used; for instance, B100 comprises of 100% biodiesel (pure biodiesel) while B20 contains 20% biodiesel and 80% petroleum diesel. In Sweden B5 is frequently used as vehicular fuel, but according to EN 590:2009 diesel standard, B7 is the highest biodiesel blend for utilization in diesel engines [5]. Recently in Nigeria, the Nigerian National Petroleum Corporation (NNPC) had decided to improve the quality of diesel being produced in the country by blending 80% fossil diesel with 20% biodiesel and this would go a long way in reducing the greenhouse gas emission [6]. Generally, biofuels can be made from vegetable oils and animal fat. However, it can be synthesized from waste oil and other non-edible oils with similar properties and potential in reducing pollutant emission from the engine without compromising quality [7]. Waste oil could be utilized as economic feedstock for biodiesel production.

Waste oil refers to vegetable oil that has been consumed for deep frying and is no longer viable for further consumption. Waste frying oil is a mixture of saturated and unsaturated monocarbxylic acids with the trihydric alcohol glyceride [8]. During frying, the chemical compositions of the vegetable oil change, as well as the physical and organoleptic properties [9]. More so, free fatty acids content are enhanced in the oil by hydrolysis of triglycerides in the presence of water from food and heat [10]. However, waste oil is available in large amount and its management constitutes a significant challenge because of its disposal problems and possible contamination of the water and land resources. In many countries, portion of this waste oil is used for soap production, while major part of it is discharged into the environment [11]. In Nigeria however, waste frying oil constitutes major waste generated in hotels, restaurants and fast food companies [12] and because, no proper policies are in place to penalize the discard of used cooking oil into flowing stream, most of these aforementioned organizations dump waste frying oils indiscriminately into rivers and landfills leading to environmentally-threatening problem [11].

Application of heterogeneous catalysts in the field of renewable energy to produce renewable fuel has become a significant area of research due to environmental concerns resulting in continual dependence on finite fossil fuel sources, current industrial energy demands and upswing in the world population. To this end, current research is focused on fuel derivable from renewable sources using heterogeneous catalyst and its utilization in the transportation industries and other industrial processes. Development of heterogeneous catalyst from biomass sources doped with naturally occurring materials for hydrocarbon (triglycerides) reactions are particular area of interest that require more attention of researchers. Few of the main solid catalysts derived biomass sources are eggshells and clay [13-14]. Based on the analysis conducted by Yung and Gon [15], the chemical composition (wt %) of chicken eggshell were obtained to be 99.0% calcium carbonate ($CaCO_3$) and 0.5% magnesium carbonate ($MgCO_3$). It is therefore visible to synthesize an active

heterogeneous catalyst from eggshell due to the high $CaCO_3$ composition, minimum environmental impact and its availability in abundance [16]. Successful usage of waste chicken eggshells as source of CaO for biodiesel production has been reported [8, 17-18].

As reported by Olutoye and Hameed [14], thermally treated clay has been employed as a highly active heterogeneous catalyst for transesterification of waste cooking palm oil. More so, Prakash *et al.* [19] successfully used Mn^{+}-montmorillonite clay as catalyst for transesterification of dicarboxylic acid with a variety of alcohols. Recently, Olutoye *et al.* [20] synthesized methyl esters/biodiesel from waste cooking oil using barium-modified montmorillonite K10 catalyst. Therefore, in this present study, a composite anthill-eggshell promoted Ni-Co mixed oxides was employed as catalyst for transesterification of waste frying oil to produce biodiesel for use as substitute in compression-ignition diesel engines.

Materials and Methods

Material

The type II anthill employed is situated in Ado-Ekiti Nigeria on an elevation of 1165 ft above sea level, having latitude (N007°36.409/) and longitude (E005°18.627/) with height and base of 2.59 m and 4.60 m was sprayed with insecticide before it was harvested. The chicken eggshells and waste frying oil (WFO) were both collected from student's cafeteria 2, Afe Babalola University (ABUAD), Ado-Ekiti Nigeria. The waste frying oil collected was purified and characterized based on its physico-chemical properties. The acid value, free fatty acid and saponification value of the WFO are 3.945 mg KOH/g, 1.973 wt% and 183.1 mg KOH/g, respectively. The synthesis-grade methanol, cobalt (II) trioxonitrate (IV) hexahydrate ($Co(NO_3)_2).6H_2O$) and nickel (II) trioxonitrate (IV) hexahydrate ($Ni(NO_3)_2.6H_2O$) were purchased from Nizo chemical enterprise, Akure Nigeria.

Preparation of Catalyst

The collected waste chicken eggshells were thoroughly washed with clean water to remove the leftover of organic matter, inner white membrane and impurities adhered to the surfaces and then subsequently re-washed. The washed eggshells were dried in an oven at a temperature of 110 ^{o}C for 2 h to get rid of water. The dried eggshells were ground to fine powder with the use of electric grinder and then sieved through 300 μm mesh size to obtain particle size of less than 0.3 mm. Similarly, the harvested anthill clay was ground with the combination of mortar and pestle and screened with the same procedure earlier considered as with the eggshell. The prepared eggshell powder, fine anthill clay, $Co(NO_3)_2.6H_2O$ and $Ni(NO_3)_2.6H_2O$ were weighed and mixed in 69.7 wt%, 17.4 wt%, 8.6 wt% and 4.3 wt% proportion of eggshell, anthill, cobalt nitrate hexahydrate and nickel nitrate hexahydrate, respectively and fed into a beaker. Substantial amount of distilled water was added to the mixtures to form suspensions. The pH of the resulting slurry was adjusted by adding 0.1 M Na_2CO_3 solution and then age in a fume hood at 80 ^{o}C for 2 h under agitation. The solution was then filtered with filter papers and oven dried at 110 ^{o}C for 12 h. The resulting dried mixture was calcined in a muffle furnace under static air conditions at a temperature of 1000 ^{o}C for 4 h. The heating rate used was 10 ^{o}C/min.

Characterization of Catalyst

The Fourier Transform Infrared Radiation (FTIR) spectrometer (IRAffinity-1S, Shimadzu) was used to identify different functional groups present in the as-synthesized catalysts. Scanning Electron Microscope (SEM) was used on the as-synthesized catalysts to identify the surface topography or morphology.

Biodiesel production process

The production of biodiesel via transesterification of waste frying oil (WFO) using anthill-eggshell promoted Ni-Co mixed oxides (NiCoAE) as catalyst was carried out under favourable reaction conditions of 3.0 wt% catalyst loading, 12:1 methanol to oil ratio, 70 ^{o}C reaction

temperature and 2 h reaction time [21]. The reaction process was conducted by placing two necks conical flask of 250 mL capacity couple with condenser and thermometer on temperature controlled magnetic stirrer device (Model no: SP131010-33 Thermo scientific). A total of 100 mL of WFO was used for each production with 48 mL and 2.74 g of methanol and NiCoAE catalyst, respectively. The stirring rate was kept constant throughout the reaction.

After completion of the biodiesel production, the product formed was poured into a separating funnel and left overnight for proper separation of biodiesel, glycerol and catalyst. Three distinctive layers were formed, with the mixture of biodiesel and unreacted methanol being the top product, followed by glycerol and lastly the catalyst. Glycerol and catalyst were removed from the product, and the fatty acid methyl ester (FAME) that formed was stored as biodiesel. Thereafter, the biodiesel sample obtained was placed on hot plate operated at 65 ^{o}C for 1 h to evaporate excessive amount of methanol. Moreover, the synthesized biodiesel was characterized by FTIR and gas chromatograph-mass spectrometer analyses.

Preparation of Different Blends of Biodiesel and Petroleum Diesel

In this study, three different blends were prepared by mixing a known volume of the biodiesel produced with certain volume of petroleum diesel obtained from NNPC mega filling station, Ado-Ekiti Nigeria, in a plastic container with the aid of a stirrer operated at constant speed of 400 rpm. The prepared blends, B20, B50 and B80 contained 20%, 50% and 80% biodiesel respectively. Similarly, sample containing 100% biodiesel was labeled as B100. The major physical properties of the blends of biodiesel and petroleum diesel which include specific gravity, kinematic viscosity, lower heating value (LHV) and flash point were measured and compared with those data reported in literature. However, the lower heating value (LHV) of biodiesel blend was determined by Equation 1 [22].

$$LHV = -0.167\rho + 184.95 \quad (1)$$

Performance Evaluation and Emission Characteristics of Biodiesel Blended with Petroleum Diesel in Diesel Engine

The gas emission of each of the three different blends was measured according to a method reported in a previous study [21]. The technical features of the combustion engine used were as presented in Table 1. The first blend used was B20, it was poured into the fuel tank of the ignition engine and the engine was immediately turned on by hand whirling. Thereafter, the probe of the gas analyzer was attached to exhaust pipe of the engine. The diesel engine was allowed to work for about 20 minutes in order to make it stabilize and allow the thick smoke to escape. The measurement was then taken by gas analyzer every 5 minutes for 20 minutes and the values of the emission measurements were stored on an input computer program to determine the average values. The same procedure was employed for B50 and B80.

Table 1: Technical features of the diesel engine (Yoshita S195NM)

Technical Variables	Technical Data
Engine type	Single-cylinder, horizontal, water cooled, four-stroke, direct injection.
Number of cylinder	One
Declared speed	2,000 rpm
Compression ratio	20:1
Rated power	3.32 kW
Overall dimensions	900x440x760 mm
Bore and stroke	95x115 mm
Starting method	Hand cranking
Combustion system	Swirl

Results and Discussion

Catalyst Characterization

The Fourier transform infrared analysis as shown in Figure 1 was carried out on raw and thermally treated NiCoAE catalysts. The spectra obtained for the two different samples are interpreted in Table 2.

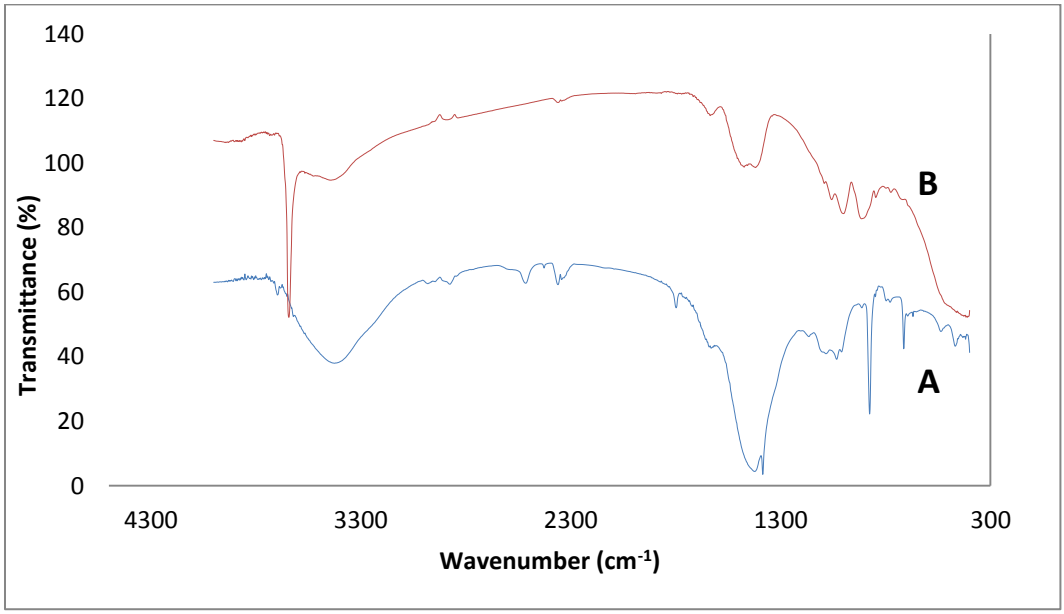

Figure 1: FTIR spectra of A-raw NiCoAE and B-calcined NiCoAE

Table 2: The major absorption band and assignment for raw and calcined NiCoAE catalyst

IR Band	Wavenumber (cm^{-1})		Assignment
	Raw NiCoAE	Calcined NiCoAE	
1	3423.76	3643.65	Bonded O-H stretching vibration
2	2360.95, 2513.33	-	symmetric stretching of the C-H bonds
4	1797.72	-	C=O functional group contained in aldehydes
5	-	1473.66	CH_3 antisym deformation
6	1421.58	1417.73	Vinyl C-H in-plane bend
7	1384.94	-	C-CH_3 deformation
8	-	1057.03	P-O-C strongest band for aliphatic amines
9	-	999.16	C-H out of plane bend of alkenes
10	-	914.29	presence of silicate ion
11	875.71	-	C-O out of plane bend vibration modes of CO_3^{2-}
12	713.69	-	C-O in plane bend vibration modes of CO_3^{2-}
13	-	505.37	Al-OH stretching vibration or the sulphate vibration band width
14	-.	428.21	CaO vibration

The presence of those functional groups contained in Table 2 confirmed the better activity of NiCoAE catalyst and this observation is in trend with the experimental result reported in the research carried out on active clay-based catalyst [14] and CaO based catalyst synthesized from chicken and ostrich eggshells [8].

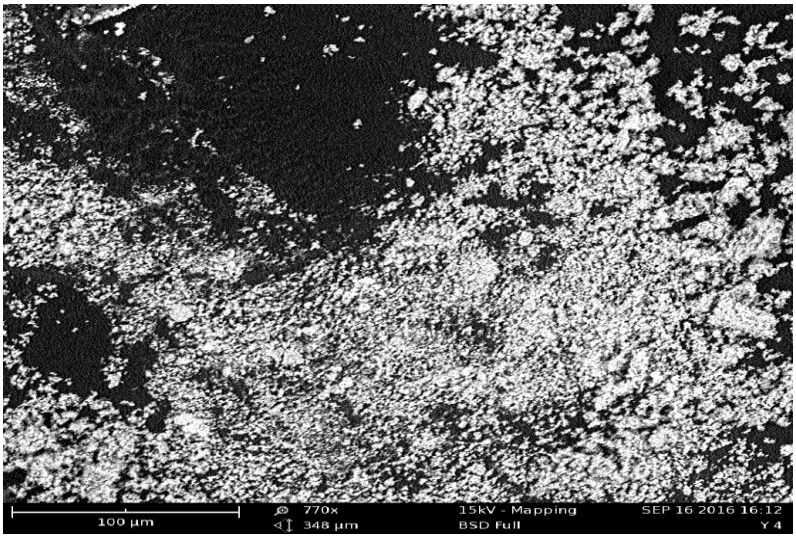

Figure 2: SEM image of calcined NiCoAE catalyst

Figure 2 shows the SEM image of calcined NiCoAE catalyst. The SEM analysis result revealed that the particles that make up the catalyst are very fine and regular in shape. This is attributed to the fact that the adequate mixing proportion of the catalyst constituents and appropriate preparation method were adopted. Moreover, the calcination temperature considered is unfavourable to moisture content, organic matters and adsorbed gases contained in the raw catalyst, which were later removed after thermal treatment, thus transforming into highly active mixed metal oxides that have closed interaction.

Characterization of waste frying oil biodiesel and fossil diesel

Fourier Transforms Infrared (FTIR) Analysis

The composition and functional groups of prepared biodiesel and fossil diesel samples were confirmed by FTIR analysis. The major absorption bands contained in displayed Figure 3 are thus interpreted in Table 3:

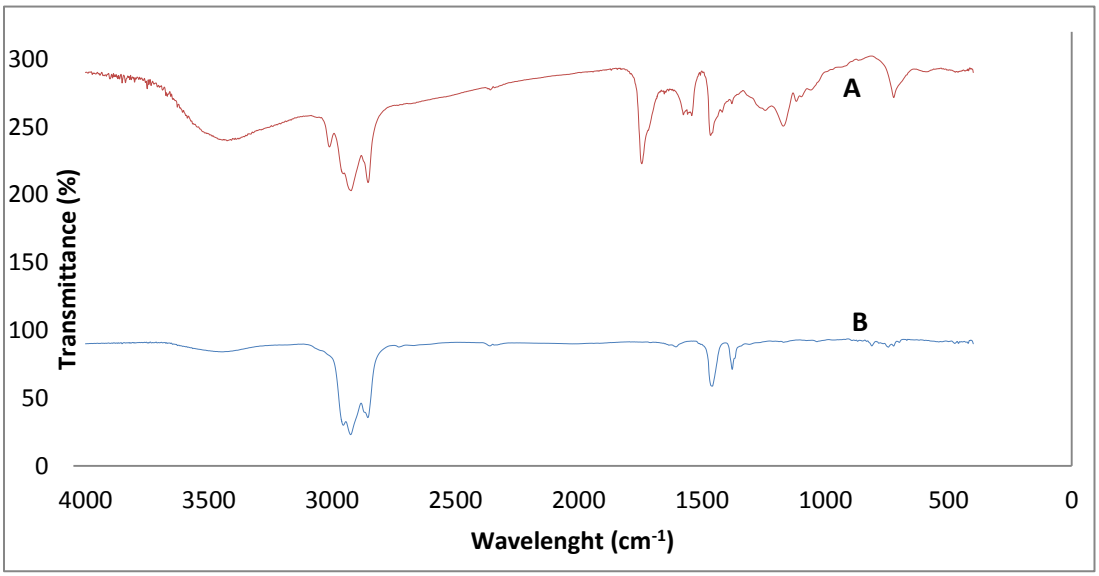

Figure 3: FTIR spectra of A-biodiesel and B-fossil diesel

Table 3: The major absorption band and assignment for biodiesel and fossil diesel

IR Band	Wavenumber (cm^{-1})		Assignment
	Biodiesel	Fossil diesel	
1	3425.69	3446.91	Bonded O-H stretching vibration
2	2922.25	2924.18	Two bands for $–CH_2$- groups
3	2854.74	2854.74	CH stretching modes
4	1743.71	-	C=O stretch of ester carbonyl
5	1462.04	1460.16	CH_3 antisym deformation
6	-	1377.22	CH_3 deformation (two bands)
7	1168.90	-	C-O stretching of esters
8	1116.82	-	C-O-C stretch ethers of aliphatic ethers
9	-	810.13	CH out of plane deformation
10	721.40	-	C-H_2 methylene rock

The presence of these functional groups confirmed the quality of the produced biodiesel and this observation is in trend with the results reported by Yadav *et al*. [26]. However, despite the fact that biodiesel and fossil diesel are synthesized from different sources, they still have some functional groups in common. The result obtained herein implies that both diesels are similar in terms of qualities and features. Hence, biodiesel remains the best alternative fuel to fossil diesel. Meanwhile, the characteristic peak at 1743.71 cm^{-1} which is strongest in the spectrum is assigned to carbonyl functional group (C=O with the stretching vibration mode). This functional group confirms the presence of esters and is only attributed to biodiesel. As a result of this uniqueness, it seems to be higher in quality than fossil diesel [3].

Gas Chromatography–Mass Spectrometry (GC-MS) Analysis

The biodiesel prepared under aforementioned reaction conditions was analyzed by gas chromatograph- mass spectrometer to determine the chemical composition of fatty acid methyl esters. Figure 4 and Table 4 display the results of various fatty acid methyl esters profile for biodiesel derived from waste frying oil (WFO).

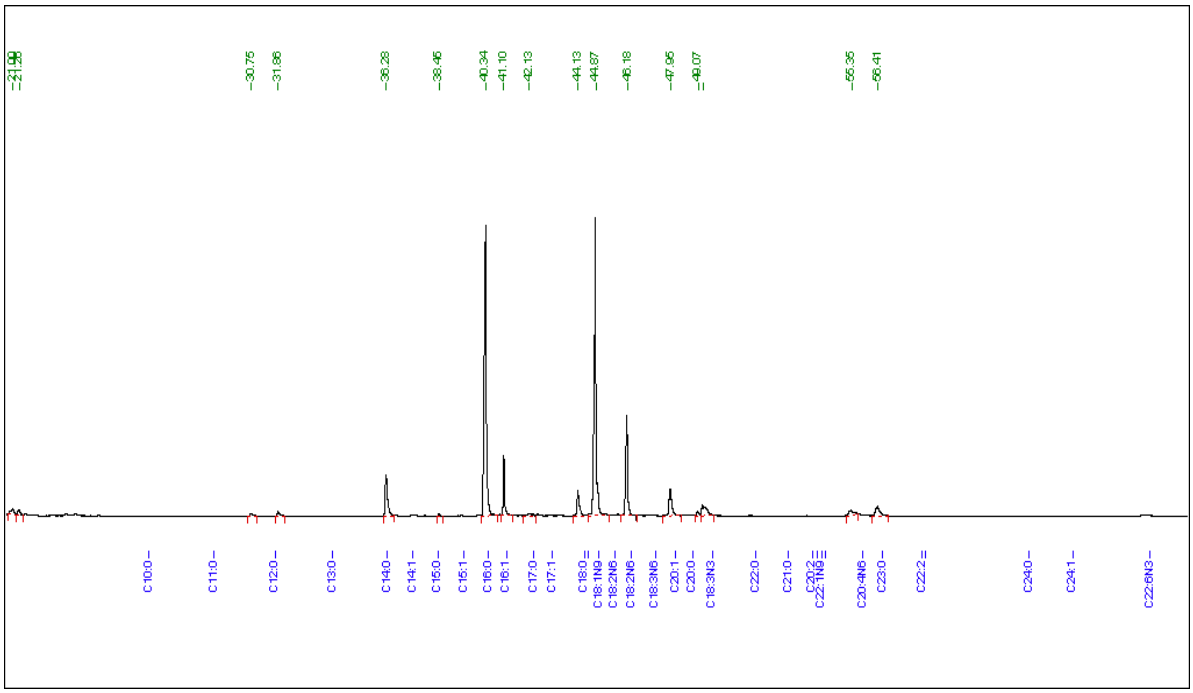

Figure 4: GC chromatogram of WCO derived biodiesel

Table 4: Composition of waste frying oil derived biodiesel

No	Component Name	Chemical formula	Retention time (min)	Area (%)
1	Lauric acid methyl ester	$C_{13}H_{26}O_2$	31.858	0.42
2	Myristic acid methyl ester	$C_{15}H_{30}O_2$	36.278	0.42
3	Pentadecanoic acid methyl ester	$C_{16}H_{32}O_2$	38.446	0.13
4	Palmitic acid methyl ester	$C_{17}H_{34}O_2$	40.342	22.09
5	Palmitoleic acid methyl ester	$C_{17}H_{32}O_2$	41.098	2.81
6	Margaric acid methyl ester	$C_{18}H_{36}O_2$	42.135	0.33
7	Stearic acid methyl ester	$C_{19}H_{38}O_2$	44.130	2.17
8	Oleic acid methyl ester	$C_{19}H_{34}O_2$	44.875	27.18
9	Linoleic acid methyl ester	$C_{19}H_{34}O_2$	46.176	6.72
10	Paullinic acid methyl ester		47.946	2.65
11	Arachidic acid methyl ester	$C_{21}H_{42}O_2$	49.071	0.30
12	α -linolenic acid methyl ester	$C_{19}H_{32}O_2$	49.275	1.73
13	Arachidonic acid methyl ester	$C_{21}H_{34}O_2$	55.350	0.62

From the Table 4, it can be observed that the main methyl esters in waste frying oil (WCO) derived biodiesel are Oleic acid methyl ester (Oleate), Palmitic acid methyl ester (Palmitate), Linoleic acid methyl ester (Linleate), Paullinic acid methyl ester, and α -linolenic acid methyl ester. Gladly, the GC-MS did not reveal the presence of any soap-like material, which indicates that the catalyst was able to handle saponification. The activity in handling saponification was attested to by the GC-MS result.

Comparison of Physicochemical and Fuel Properties of Biodiesel and Its Blends

The main properties which include specific gravity, kinematic viscosity, lower heating value (LHV) and flash point of different blends of biodiesel and petrol diesel were measured and the results are presented in Table 5.

Table 5: Physical and chemical properties of WFO derived biodiesel and its blends

Property	Unit	B20	B50	B80	B100
Specific gravity/Density	g/cm^{-3}	0.866	0.825	0.872	0.883
Kinematic viscosity	mm^2/s	3.31	2.27	2.23	3.76
Lower heating value (LHV)	MJ/kg	40.33	47.18	39.33	37.49
Flash point	^oC	130	79	124	162

The physical and chemical properties of different blends of biodiesel and petrol diesel as contained in Table 5 above indicate that the specific gravities/densities of those blends and pure biodiesel vary in the range of 0.825-0.883. The densities of B20 and B80 being within ASTM standard (0.86-0.90 g/cm^3) indicates that these blends are of good quality. However, B50 may require modification as its density is less than 0.86 g/cm^3.

The kinematic viscosities of all the three blends and that of the biodiesel fall within ASTM standard range of 1.9 and 6.0 mm^2/s. This behaviour can be attributed to homogenized mixture, which might have resulted from adequate mixing of biodiesel and petrol diesel. Meanwhile, these values as seen are higher than that of biodiesel fuel (2.05 mm^2/s) indicating that biodiesel has large molecular mass [27]. However, the values of viscosities of the three blends were less than that of pure biodiesel (3.76 mm^2/s). This implies that blending brings about reduction in viscosity. Hence, indicating a complete combustion, better atomization and lower emissions of unburned hydrocarbons and smoke [28].

An important criteria in determining the combustion quality of fuel is the energy content (calorific value). This is due to the fact that biodiesel contains 11% oxygen by weight [29], thus biodiesel has lesser lower calorific value as compared to that of petrol diesel [30]. Table 5 displays the result of lower heating value (LHV) of B20, B50, B80 and B100. It was observed that B50 had the highest value, which implies that the energy released of B50 combustion is the highest, followed

by B20. However, the lower heating values of those biodiesel blends (B20, B50 and B80) are higher than that of pure biodiesel. A similar observation was also reported by Tesfa *et al*. [22] in the prediction models and LHV effect on the CI engine performance when fueled with biodiesel blends.

Flash point is referred to as measure of flammability of the fuel [1]. The values of flash points obtained for the B20, B50 and B80 samples were 130, 79 and 124 ^{o}C indicating a significant drop when compared to that of B100. This indicates an improvement in fuel qualities.

Performance and Emission Characteristics of Different Blended Fuels in Diesel Engine

In this aspect, the gas exhaust emissions are compared for different biodiesel blends, that is, B20, B50 and B80 at the engine speed of 2,000 rpm. The gas emissions measured included carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2). The gas analyzer used in this study could only measure those aforementioned gases.

Comparison of Carbon monoxide (CO) Emission

The carbon monoxide (CO) exhaust emissions for the three biodiesel blends are presented in Figure 5. Larger concentration of CO was emitted when the diesel engine was fueled with B80 fuel, followed by B50 which released 1,055 ppm and least CO was emitted from diesel engine when it was fueled with B20 blended fuel. Although, the amount of CO emitted for every blended fuel was found to be very small.

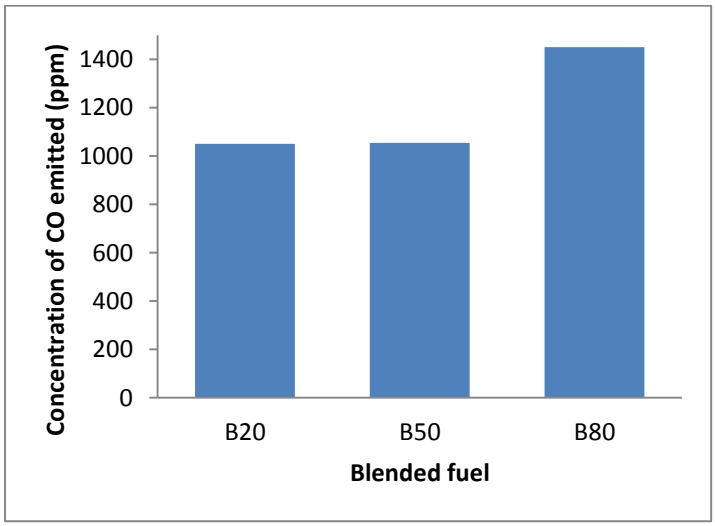

Figure 5: CO emission pattern for B20, B50 and B80 blended fuel

There was no much difference among the three blended fuels. A similar observation was also reported by Monyem and Van Gerpen [31], who observed that the blends of biodiesel lowered CO emissions. Moreover, high oxygen content of biodiesel enhances combustion and leads to reduction in CO emission. It is noticed that the three blended fuels have lower values of CO as compared to other gases emitted. This indicates that the combustion was almost completely done.

Comparison of Carbon dioxide (CO_2) Emission

For the CO_2, and as it was widely reported in the literature, that one of the unique qualities of biodiesel is that it provides a means of reusing CO_2, so there is no net increase in global warming [23]. According to the Figure 6, it was observed that B80 fuel has higher CO_2 emission, followed by B50 fuel and this implies that CO_2 emission increases as the volume of biodiesel increases in the mixture of biodiesel and fossil diesel.

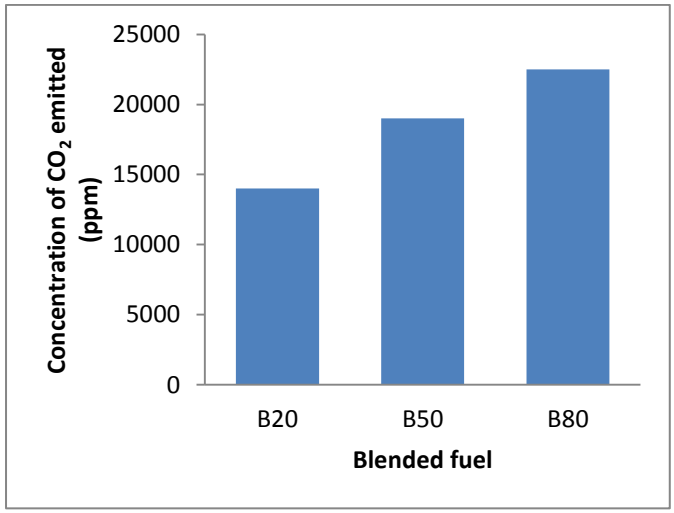

Figure 6: CO_2 emission pattern for B20, B50 and B80 blended fuel

Moreover, it is a known fact that complete combustion inside the combustion chamber of diesel engine promotes CO_2 [1]. Besides, it has been reported by many researchers that presence of O_2 in biodiesel enhances better combustion [32-33], which helps to convert CO into CO_2 and therefore, increases CO_2 emission rate. This is attributed to why B80 fuel released large amount of CO_2 as compared to other blended fuels.

Comparison of Oxygen (O_2) Emission

In the case of O_2, the reported results for the three blended fuels are larger than the values of CO_2 and CO emitted and this is because biodiesel has high content of oxygen [23]. However, an increase in oxygen concentration was noted, as can be seen in Figure 7, when biodiesel content in biodiesel-diesel blend was 20% (B20) compared to those with 50% (B50) and 80% (B80) and the most probable reason behind this might be due to the lower elemental carbon to hydrogen ratio in biodiesel [1].

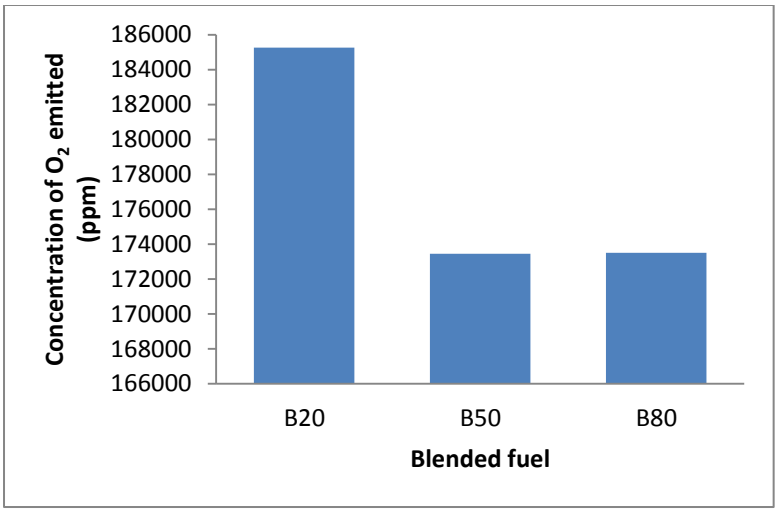

Figure 7: O_2 emission pattern for B20, B50 and B80 blended fuel

This could also be corroborated by the values of volumes of CO and CO_2 emitted when the engine was fueled with B20, there were decrease in CO and CO_2 emission compared to those recorded for B50 and B80. Hence, less oxygen was consumed during combustion of B20 fuel.

Conclusion

In this work, the preparation and characterization of anthill-eggshell promoted Ni-Co mixed oxides catalyst, and its application in transesterification of waste frying oil have been investigated. Both FTIR and SEM analyses performed showed that the developed catalyst was of good quality.

The NiCoAE catalyst was found to be highly effective toward conversion of waste frying oil and able to achieve nealy 100% of biodiesel at reaction temperature of 70 ^{o}C, reaction time of 2 h, catalyst loading of 3 wt% and methanol to oil molar ratio of 12:1. Moreover, the biodiesel produced was blended with petroleum diesel in three different proportions (B20, B50 and B80) and were tested on diesel engine to evaluate their performance and emission characteristics. The blended fuel containing 20%v/v biodiesel content (B20) emitted lowest percentage of CO and CO_2. The result obtained herein indicates that the mixture of biodiesel and petroleum diesel containing 20% biodiesel content (B20) emitted less carbon monoxide (CO) and carbon dioxide (CO_2), thus, indicating best dual fuel combination.

Acknowledgement

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