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Conversion of orange peel to biodiesel and its investigation as an alternative fuel in compression ignition engines

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ABSTRACT

Orange peels are considered a waste, and the increase in cultivation and processing of oranges tends to increase waste in society. This work is designed to convert waste to wealth by investigating the potential of biodiesel production from orange peels and its suitability as an alternative fuel in compression ignition (CI) engines. Steam distillation pilot plant was used to extract oil from the orange peels, 1.27% was its maximum oil yield recovery. The oil was transesterified using methanol at a 6:1 molar ratio with 0.70% sodium hydroxide as the catalyst at 55 °C for 60 minutes and 96.00% biodiesel yield recovery was obtained. The biodiesel properties were found with density of 872 kg/m^3, viscosity of 1.9 cSt, pH value of 7.6, calorific value of 38.4 MJ/kg, and flash point of 84 °C. The biodiesel was blended with diesel at different volumes, compared with pure diesel, and run on a CI engine. B20 (20.00% biodiesel, 80.00% diesel) has the optimum brake-specific fuel consumption rate and brake thermal efficiency and are respectively 9.08% lower and 11.99% higher than petroleum diesel. B15 (15.00% biodiesel, 85.00% diesel) has the optimum exhaust temperature and is 10.37% lower than diesel. B10 (10.00% biodiesel, 90.00% diesel) has the optimum carbon monoxide and carbon dioxide emissions and are 58.07% and 43.70% lower respectively than petroleum diesel.

Keywords: orange peel, biodiesel, fuel gas emission, CI engine performance evaluation

INTRODUCTION

The compression ignition (CI) engine is without a doubt one of the important engines for the modern day. Its existence has brought success and development to the transportation, construction, agricultural, and power sector, as it is fondly used to power heavy-duty machines because of its higher thermodynamic efficiency. Diesel is mainly used to fuel CI engines and has proven to be highly efficient. Diesel produced from petroleum (petro-diesel) is classified to be among fossil fuels.

The emission impact of fossil fuels on the greenhouse effect, humans, and the environment is on the rise. More so, fossil fuels are non-renewable, and their reserves are diminishing. Current energy policies incorporate core energy transition issues, including energy technologies and the environment, to achieve clean energy, increase energy efficiency, and work on climate change. These developments have led to an increment in the use of biomass, since it is considered a renewable energy resource and has the potential to contribute significantly to the global primary energy supply, produce low carbon emissions, and is capable of mitigating climate change. Among biomass is biodiesel.

Biodiesel is now more considered because its sources are renewable, and its use benefits the environment. Biodiesel is liquid fuel from agricultural products for CI engines. Biodiesel contains some measure of oxygen, which aid complete combustion and lower exhaust emissions. Biodiesel is made from the extracted oil of both edible and non-edible vegetable oils and animal fats. Various extraction techniques are used in their extraction, including cold press, distillation, ultrasound, microwave, and thermo-mechanical process amongst others. Ferhat et al. (2007) underlined losses of some volatile compounds, low extraction efficiency, degradation of unsaturated or ester compounds through thermal or hydrolytic effects, and toxic solvent residue as deficiencies that may occur during extraction. Thus, the separation technique that should be employed for their extraction can be centered on the type of feedstock, availability of extractor, expected quality and quantity of oil needed, cost, and purpose for extraction.

These oils use for biodiesel have similar physio-chemical properties to that of conventional diesel. The act of using them directly as fuel in the engine without chemical alteration is called straight vegetable oil (SVO). SVO is said to be problematic. The extracted oils have high viscosity and low volatility, and do not burn off completely (Schuchardt et al., 1998) causing problems in pumping and atomization, ring

Figure 1. Orange peels (Source: Authors)

sticking, and forming deposits in the engine (Kaushik et al., 2014), producing a lower performance and gives higher smoke emissions (Rao et al., 2009), which leads to reduction of the engine's life span. One of the measures to improve their quality and make them more suitable and safer to run on CI engines is by processing the oils through transesterification.

A transesterification reaction is a chemical reaction of triglyceride and short-chain alcohol in the presence of a catalyst to produce alkyl esters (biodiesel) and glycerol. The reaction reduces the viscosity of vegetable oil, maintains its heat values, and increases its cetane number. The type of catalyst (alkaline or acid), alcohol/vegetable oil molar ratio, temperature, purity of the reactants (mainly water content), and free fatty acid content are vital factors that influence transesterification results (Schuchardt et al., 1998), they determine yield of biodiesel (Leung et al., 2010), and as such influence the characteristics of the fuel. Methanol or ethanol with a base catalyst (potassium hydroxide [KOH] or sodium hydroxide [NaOH]) is commonly used for the process. Methanol is used because it is readily available and affordable, reacts quickly with triglycerides, and NaOH easily dissolved in it, while ethanol is used because it is derived from agricultural products and is renewable (Ma & Hanna 1999; Demirbas, 2005).

Sweet orange (citrus sinensis) is another agricultural feedstock source of bioenergy. Orange is a readily available fruit crop grown in many countries of the world, with the year 2019's annual world production of 76 million metric tons (FAO, 2021). The fruit consists of two distinct regions: the endocarp (juice sac) and the pericarp (peel). Its peels consist of an epidermis of epicuticular wax with numerous small aromatic oil. This oil compound is found to be a mixture of hydrocarbon (HC), esters, aldehydes, alcohol, ketones, and terpenic oxide (Njoku & Evbuomwan, 2014; Qiao et al., 2008).

Orange peel (**Figure 1**) oil is fondly used for aromatherapy, anti-septic, antimicrobial, flavor, and scent. Oils use for those purposes are of high quality and must maintain their therapeutic value and safety level but not all can satisfy these conditions. Njoroge et al. (2006) and Venkateshwarlu and Selvaraj (2000) highlighted the maturity of the fruit, the vegetative phase of a plant, the condition of storage, and the extract method as factors that significantly affect the composition of orange peel oil. Orange peels are inedible feedstock full of potential. From time immemorial, orange peels are used for traditional medication and insect repellent. Domestically, its peel is most times made redundant because it is seen as waste. Industrially, orange peel from orange juice processing plants in some areas is used for landfill. These peels remain underutilized and the increase in the production of oranges will result to increase in waste if they are not properly addressed. Among ways to utilize orange peel is by generating energy from them. Orange peel has been experimented with in diverse ways to produce bioenergy in diverse forms, it includes biogas (Wikandari et al., 2015), bioethanol (Gomaa, 2013), energy through pyrolysis (Aguiar et al., 2008), solid biofuel (de Morais et al., 2015), bioelectricity (Miran et al., 2016), and biodiesel (Bull & Obunwu, 2014).

Most oils used so far to produce biodiesel are from edible feedstock, expensive, and may thus be counterproductive if used on a large scale to produce biodiesel (Yusuf et al., 2011), they may result in food scarcity. Using sweet orange peel to produce biodiesel can give cheap clean fuel since it is inedible feedstock. Work has been done on orange peels to biodiesel, and the performance of the fuel on the CI engine, but they are limited. This research will focus on the production of orange peel biodiesel and its behavior in CI engines. It entails extracting oil from orange peel using the physical method and characterization of the orange peel oil, converting the oil into biodiesel by transesterification and characterization of the biodiesel, and conducting performance and emission evaluation of the biodiesel on CI engine.

METHODOLOGY

Material and Equipment

The materials and equipment used for this research include; sweet orange peels, hot plate with magnetic stirrer, NaOH, methanol, round bottom flasks, beakers, separation funnel, distilled water, reflux system, thermometer, refrigerator, stopwatch, steam distillation pilot plant (**Figure 2**), density bottle, setaflash series three flashpoint tester, NDJ-7 rotational viscometer, HI 2211 pH/ORP meter, oxygen bomb calorimeter, 165F 1-cylinder 4-stroke IC engine, techquipment TD 115 hydraulic dynamometer & techquipment TD 114

Figure 2. Steam distillation plant (Source: Authors)

Figure 3. Engine set up (Source: Authors)

Table 1. Engine specification

Variable	Specification
Model	165F
Type	Horizontal single cylinder four-stroke & air-cooled
Bore (mm)	65
Stroke (mm)	70
Rated output (12 hours power rating) (kW)	2.43
Maximum torque (N/m)	12
Rated speed (rev/min)	2,600
Method of cooling	Air cooling by blower
Compression ratio	20.5-22.0
Specific fuel compression rated output (g/kwh)	<284.2

instrumentation unit, and eagle X2-C155 flue gas analyzer (**Figure 3** and **Table 1**).

Collection and Preparation of Sample

Orange peels were collected from fruit market. Fresh Orange peel and dry orange peel were collected separately in different batches in jute sacks. Each of the batches amounted to the available peel at the time of collection. Fresh peels were stored in a refrigerator to maintain their freshness, while dry peels were degraded and stored in a dry place at room temperature till the time of extraction.

Extraction Process

With commercial production in mind, steam distillation pilot plant was selected and used as the oil extractor. The extractor consists of a boiler, extraction chamber, conveying pipe, condenser, coolant, and separation pipe. Inside the extraction chamber, is a removable drum that houses feedstock. As collected in batches, the peels were poured into the extraction chamber of the extractor without any pretreatment. The extractor is powered by both electricity and liquefied petroleum gas. Each extraction lasted for 180-240 mins, and the batches were processed until oil is no longer coming forth after a considerable waiting period. After the oil has obtained, their yield recovery was determined.

Production of Biodiesel

The transesterification of the oil into biodiesel was conducted in the laboratory. The extracted oil was transferred to a round bottom flask, and methanol in which 0.70% NaOH catalyst has been dissolved was added to the extracted orange peel oil in a round bottom flask in a 6:1 molar ratio. The reflux condenser was attached to the round bottom flask and the solution was stirred on a magnetic hot plate for 60 minutes at 55 ^{o}C.

This chemical process produced methyl ester (biodiesel) and glycerol. After the reaction time, the mixture of biodiesel with glycerol was transferred to a separating funnel, where it was allowed to stand for 24 hours, the glycerol was separated from the biodiesel after which the biodiesel was washed several times with warm distilled water to remove the remaining glycerol and other impurities until a clear down layer was observed. The biodiesel was air-dried until no droplet of water was observed and then oven-dried at 110 ^{o}C above the boiling point of water until a constant weight was obtained. Yield recovery was determined for the process.

Table 2. Emission analyzer range & accuracy

Parameters	Range	Accuracy
CO (ppm)	0-4,000	1/±10<100, ±5>100
CO_2 (%)	0-20	0.1/±0.3

Determination of Fuel Properties

Fuel properties of orange-peel oil and its biodiesel were determined, as follows: viscosity was determined using a rotational viscometer in accordance with ASTM D2196 standard. Flashpoint was determined using setaflash three closed cup in accordance with ASTM D3278. Density bottle was used to determine their density at the temperature of 20 °C. Bomb calorimeter was used to determine their calorific value in accordance with ASTM D240 standard. pH values were determined using a pH/ORP meter at a temperature of 25 °C.

Performance and Emissions Evaluation of Biodiesel in CI Engine

Performance and emissions of orange peel biodiesel on CI engine were conducted on an unmodified 1-single cylinder 4-stroke CI engine fueled with various biodiesel-diesel blends fuel samples and petroleum diesel. Lower percentage of biodiesel blends was considered and used because it is the recommended volume for biodiesel in CI engines. The biodiesel was blended with diesel at 5.00% (B5), 10.00% (B10), 15.00% (B15), 20.00% (B20), 25.00% (B25), and 30.00% (B30) to know the most efficient blend ratio of orange peel biodiesel with diesel for CI engine. Each test compared blended fuel samples to pure diesel (D100).

Table 2 shows the engine specification. The engine was mounted with techquipment TD 115 hydraulic dynamometer, which transducers measuring the engine torque and speed and displayed in the instrumentation unit and techquipment TD 114 instrumentation unit, which indicates the measures of air and fuel consumption rate and exhaust temperature. The engine speed was raised slightly and then allowed to run idle for 10 minutes as a preparatory measure before the experiment. On each sample, four levels of load, varying the speed and torque as such increase the brake power. The fuel flow rate was measured by shutting off the fuel tap, so the fuel was consumed only from the pipette. A stopwatch was used to measure the time taken to consume 8ml of fuel from the pipette. Eagle X2-C155 flue gas analyzer was attached to the engine exhaust to measure each fuel's carbon monoxide (CO) and carbon dioxide (CO_2) values at each experiment.

RESULTS AND DISCUSSION

Extraction and Yield Recovery

Oil extraction from dry orange peels fail after some trials, but it was successful with fresh peels. **Table 3** presents the summary of the extraction process.

Table 3. Summary of extraction process

Batch	I	II	III	IV	V	VI	VII
Mass of peel (kg)	11.8	13.5	6.8	11.0	13.2	11.8	6.2
Volume oil recovered (ml)	170	30	55	80	20	120	55
Yield recovery %	1.27	0.20	0.71	0.64	0.13	0.89	0.78

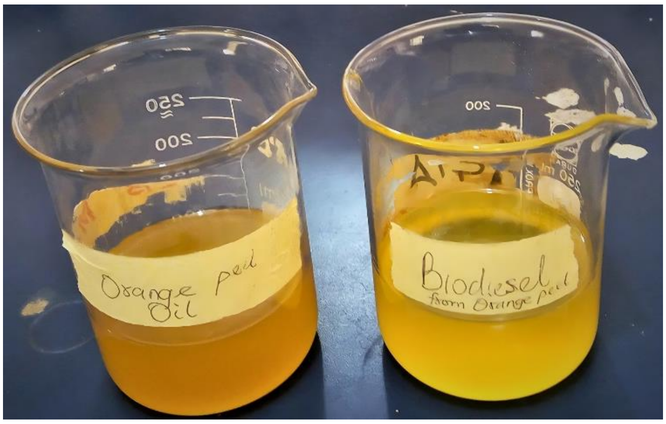

Figure 4. Orange peel oil & its biodiesel (Source: Authors)

Figure 5. Dead orange peels (Source: Authors)

Seven batches of the extraction process produced 530 ml of orange peel oil (**Figure 4**). It can be observed that there is variation in oil recovery. Batch (I) produced the maximum yield of 1.27% from 11.8 kg while batch (V) produced to lowest yield of 0.13% from 13.2 kg. The result is influenced by the difference in varieties of the peels, the state of the peel when collected, the time of extraction, and the nature of the extractor. This maximum yield of 1.27% is higher than 0.55% (30 ml oil from 4.5 kg peel with 825 kg/m³) and lower than 2.06% oil yield obtained by Bull and Obunwu (2014) and Rezzoug and Louka (2009), respectively using steam distillation method. After extraction, the orange peels decolorized to dark brown and dropped in weight (**Figure 5**). From the transesterification process, 96.00% biodiesel yield recovery was obtained.

Fuel Characteristics

The oil obtained and its corresponding biodiesel was characterized and presented in **Table 4** along with ASTM standards. Density is an important property of fuel. It indicates the possible delay between the injection and combustion of the fuel in a diesel engine. It also influences fuel consumption. The density obtained for orange peel oil and biodiesel are 880 kg/m³ and 872 kg/m³ respectively. This orange peel biodiesel result is 5.00% denser than the 825 kg/m³ of Bull and Obunwu (2014). The variation could be influenced by the difference in, the temperature of samples at the time of the test, the method

Table 4. Fuel properties of orange peel oil & its biodiesel

Parameters	Orange oil	Biodiesel	ASTM
Density (kg/m^3)	880	872	860-890
Kinematic viscosity (cSt)	2.6	1.9	1.9-6.0
pH value	3.94	7.76	7.0-7.7
Calorific value (MJ/kg)	38.5	38.4	Varies
Flashpoint (°C)	95	84	130 min

of test, and peels species. Both the orange peel oil and its biodiesel are in the range of ASTM standards. This indicates that both the bio-oil and the biodiesel certify the density requirement for fuel that can be used on CI engines.

Flash point is the lowest temperature at which a fuel releases enough vapors to ignite. It helps to characterize fire hazards so that the fuel can be handled safely. Typically, biodiesel has higher flash point than petroleum diesel. This is because they are oxygenated fuel, and their components are less volatile. The flash points of the orange peel oil and its biodiesel are 95 °C and 84 °C, respectively. These values are influenced by the chemical composition of the extracted bio-oil. It was observed that the flash point of orange peel oil is 11.00% higher than that of its biodiesel. This reduction in value is attributed to the chemical changes during the transesterification process. Although both orange peel oil and biodiesel have lower flash points compared to ASTM standard, but they are significantly higher than petroleum diesel whose flash point range is 55 °C-66 °C and significantly lower than an average biodiesel flash point 150 °C (Gouveia et al., 2017). Orange peel oil and its biodiesel may have lower flash points compared to some other biodiesels, but they are combustible and safe to handle.

Calorific value is the measure of the volume of energy in a fuel. A higher calorific value indicates that the engine can generate more power and consume less fuel to do work while a low calorific value indicates a diminution in engine power. Calorific values of 38.5 MJ/kg and 38.4 MJ/kg are obtained for orange peel oil and its biodiesel respectively. It was observed that the transesterification process has no significant effect on the calorific value of the biodiesel. The calorific values obtained are 14.00% less for both orange peel oil and its biodiesel than that of petroleum diesel (45 MJ/kg). This can be attributed to the fact that petroleum diesel has higher hydrogen content. The produced fuels may have less calorific values but the oxygen content in them will help the fuels to burn more efficiently in CI engine.

Viscosity is the measure of the thickness of a liquid. it indicates the level of fluidity of a fuel. The fuel system or engine can be damaged if the viscosity used is too high or too low. The viscosity obtained for both the orange peel oil and its biodiesel were 2.6 cSt and 1.9 cSt, respectively. The transesterification process has a significant effect on the viscosity of the biodiesel. These values are quite lower compared to the viscosity values range of 27.2 cSt-53.6 cSt reported for vegetable oil and 3.6 cSt-4.6 cSt reported for biodiesel (Demirbas, 2009) but such is what a CI engine wants. Bull and Obunwu (2014) also found a similar viscosity value of 2.1 cSt for orange peel biodiesel, this fact establishes that orange peel biodiesel viscosity is lower than that of average biodiesel. The viscosity value of the produced orange peel biodiesel shows that the fuel is highly qualitative and will run smoothly in CI engine without damaging any element and give good fuel delivery, enabling complete combustion. The viscosity value of the orange peel oil shows that it can be used as SVO.

Table 5. A comparison of biodiesel-diesel blends & pure diesel at maximum load

Parameter	BSFC (kg/kw.h)	BTE (%)	Exhaust temp (°C)	CO (ppm)	CO_2 (%)
B30	0.2536	28.59	128	205	5.2
B25	0.2535	28.27	122	284	6.3
B20	0.2484	28.61	122	235	6.8
B15	0.2507	28.11	121	196	6.2
B10	0.2569	27.22	125	130	4.9
B5	0.2577	26.91	126	159	5.5
Diesel	0.2732	25.18	135	390	7.7

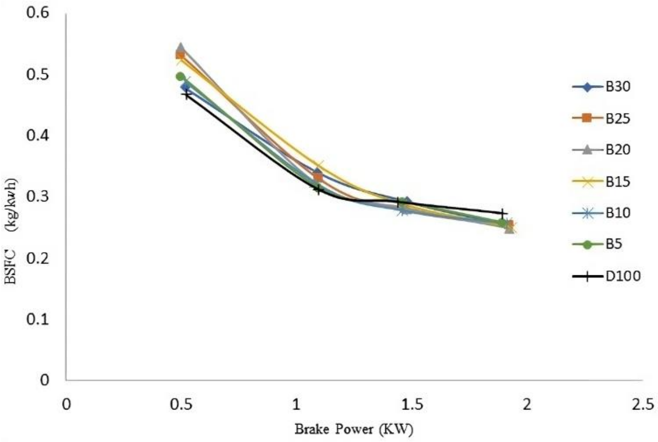

Figure 6. Brake-specific fuel consumption against brake power (Source: Authors' own elaboration)

The pH value indicates the acid-base concentrate of a sample. It is important for the pH value of a fuel sample to be neutral for the safety of an engine, especially to avoid corrosion on the engine's metallic parts. A pH value of 3.94 was obtained for the orange peel oil, which is moderately acidic. The pH value of produced biodiesel was found to be 7.76, which is neutral and in line with ASTM standards.

Performance and Emission Characteristics in CI Engine

SVO was dropped from this experiment because it is not included in the scope of this segment, only the trans-esterified fuel (biodiesel) was used. A comparison of experimental data for 5.00%, 10.00%, 15.00%, 20.00%, 25.00%, and 30.00% biodiesel blends with pure petroleum diesel on peak load is presented in **Table 5**.

Brake-specific fuel consumption

Brake-specific fuel consumption (BSFC) indicates the amount of fuel consumed by an engine for a unit of power output. BSFC is a vital parameter for fuel evaluation on an engine because it shows its level of efficiency. **Figure 6** shows the variation in BSFC between biodiesel blend and pure petroleum diesel. It was observed that the specific fuel consumption for all the blended samples was marginally higher than that of the pure diesel at the first load. As the brake power increases, BSFC of the blended biodiesel decreases, and at maximum load, BSFC of diesel is found to be higher than

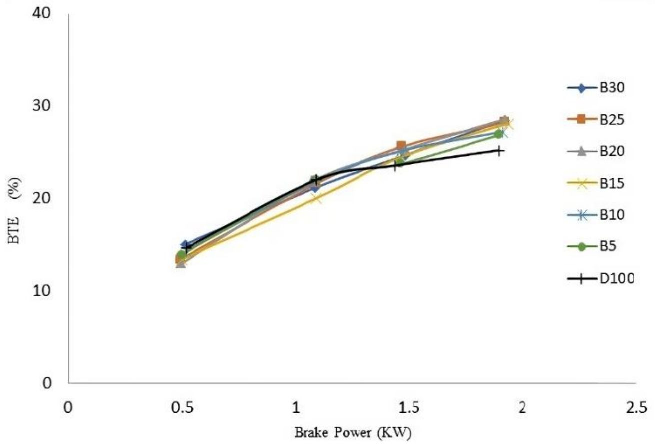

Figure 7. Brake thermal efficiency against brake power (Source: Authors' own elaboration)

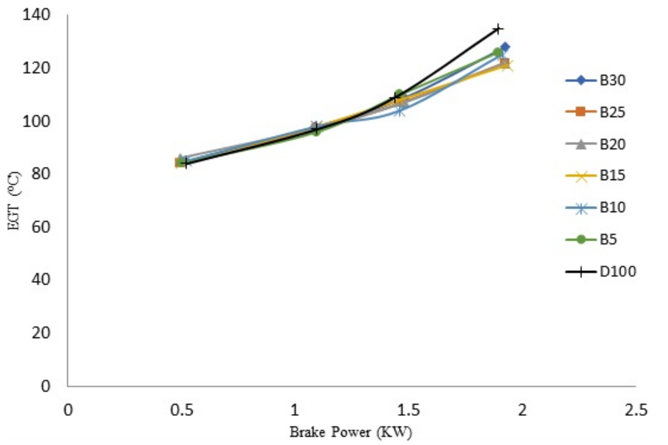

Figure 8. Exhaust gas temperature against brake power (Source: Authors' own elaboration)

that of the blend samples even with diesel having a higher calorific value than the biodiesel-diesel blends. This reaction is influenced by the fact that orange peel biodiesel is an oxygenated fuel and has lower viscosity, it also indicates the presence of a higher cetane number in the blended samples. Higher cetane number leads to an increase in the speed of oxidation and thermal cracking rate, which in turn produces lower specific fuel consumption and reduces the emission of unburned HCs (Cataluna & da Silva, 2012). Olugasa et al. (2022) reported 54.4 as the orange peel biodiesel cetane number, which is 20.00% more than the type 2 diesel cetane number. At maximum load, B20 was found to have the optimum BSFC rate and is 9.08% lesser than diesel.

Brake thermal efficiency

Brake thermal efficiency (BTE) shows how heat generated from combustion is efficiently transformed into work. **Figure 7** shows BTE variation between biodiesel-diesel blends and petroleum diesel. It was observed that BTE of all blended diesel is higher than that of pure diesel. Higher thermal efficiency for the blended samples shows that they combusted better. This is influenced by their oxygen content and lower viscosity. These factors help to produce better atomization and combustion. At maximum load, B20 was found to have the optimum BTE and is 11.99% higher than pure diesel. Higher BTE for 20.00% biodiesel blend compared to diesel at peak load conditions was also reported by Deep et al. (2013) when they evaluated the performance of orange peel oil methyl ester blend at 10.00% and 20.00% on an unmodified single-cylinder CI engine. This shows that orange peel biodiesel has a positive impact on each blend and gives better efficiency.

Exhaust gas temperature

The exhaust gas temperature (EGT) is the temperature of gases emitted from an engine through its exhaust manifold. It indicates the temperature of heat produced from the combustion process. Lower EGT indicates complete combustion while higher EGT indicates incomplete combustion. **Figure 8** shows the variation in EGT between biodiesel-diesel blends and pure diesel. As the load increased, EGT of all fuel samples increased. At maximum load, the biodiesel blends are significantly lower in EGT compared to petroleum diesel. This shows that the blended fuels performed better in the CI engine. The lower EGT for blended fuel samples is influenced by their oxygen content, higher cetane number, lower viscosity, and calorific value. These parameters combine to give a better atomization and evaporation resulting in lower EGT (Zhang et al., 2022). B15 was found to have the optimum EGT and is 10.37% lower than pure diesel.

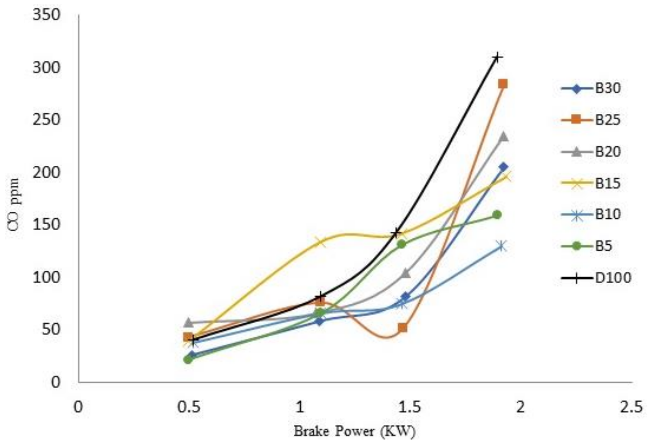

Figure 9. Carbon monoxide against brake power (Source: Authors' own elaboration)

Carbon monoxide emission

CO is one of the gases harmful to humans and the environment. High emission of this gas is not a friend to humanity. **Figure 9** shows the variation in CO emission between biodiesel-diesel blends and pure diesel. It was observed that CO blended fuel samples have lower CO emissions than pure diesel except for B15 at load two. Many researchers also found lower CO emissions for biodiesel. This outcome is influenced by the oxygen content in the biodiesel. At maximum load, B10 was found to have the optimum CO emission and is 58.07% lower than pure diesel.

Carbon dioxide emission

CO_2 is one of the greenhouse gases. Just like CO, high emission of CO_2 is bad for the environment. Mitigation of CO_2 emissions in all sectors is now a global common interest. CO_2 emission of biodiesel-diesel blends fuel was trialed along with petroleum diesel on CI engine, its result is illustrated in **Figure**

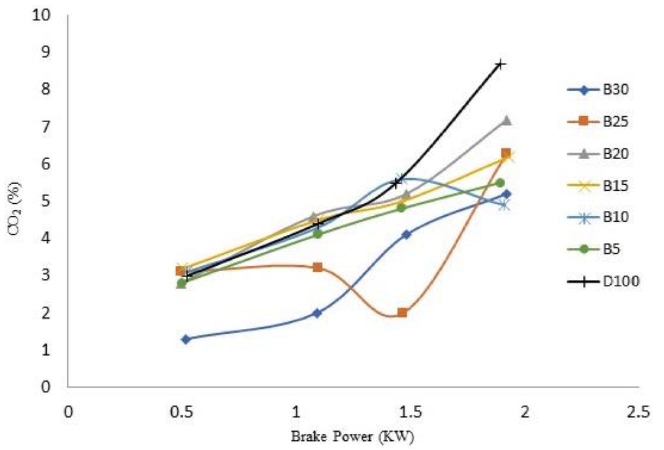

Figure 10. Carbon (IV) oxide against brake power (Source: Authors' own elaboration)

10. It was observed that blended fuel samples have lower CO_2 emissions than that of pure diesel except for B15 and B20 at load two, and B10 at load three, respectively. A significant difference was found at the maximum load between the blended samples and pure diesel, B10 was found to have the optimum carbon (IV) oxide emission and is 43.70% lower than petroleum diesel. The lower CO_2 emissions for the blends are attributed to the biodiesel chemical composition. It is an indication that orange peel biodiesel has a lower carbon-to-hydrogen ratio, which is the major influencer of lower CO_2 emission (Zhang et al., 2022).

CONCLUSIONS

Orange peels were successfully converted to biodiesel and investigated as an alternative fuel for compressive ignition engines. Orange peels may produce low oil yield compared to other biodiesel feedstock, but its product produces high-quality clean fuel with very good performance in CI engines and environmental friendly emissions. Its residue after extraction of bio-oil from it can still be used for landfill. The fact that all of the blended fuel performed better than pure diesel at maximum load, show how effective and good additive they will be if industrialized. The use of orange peel biodiesel will help to reduce carbon emissions. Using higher than lower blends in CI engines may not be suitable because the blend ratio has a major influence on its performance and emission results. Orange peel oil should also be considered for fueling CI engines, but its acidic value must be addressed before use. Converting orange peel to biodiesel will reduce waste, improve the economy, and provide a promising alternative fuel for CI engines.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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