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Impact of Biodiesel Blending on Emission Characteristics of One-Cylinder Engine Using Waste Swine Oil

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Abstract: The influence of biodiesel blending on the emission parameters of a one-cylinder engine using waste swine oil was investigated in this research. This research focused on particulate matter, nitrogen oxides, hydrocarbons, carbon monoxide, and carbon dioxide emissions at various engine speeds and biodiesel mixing percentages. According to the results, increasing the amount of biodiesel in diesel blends might result in considerable reductions in particulate matter emissions while potentially raising nitrogen oxide emissions due to biodiesel's higher oxygen content. Engine speed considerably affects hydrocarbon and carbon monoxide emissions, with biodiesel mixes benefiting more at higher engine speeds. This study also discovered that when the amount of biodiesel in a fuel blend grows, so do carbon dioxide emissions, but brake thermal efficiency drops. These findings indicate that using waste swine oil biodiesel as a fuel source has both advantages and disadvantages in terms of engine emissions, and more study is needed to optimize biodiesel consumption and reduce nitrogen oxide emissions.

Keywords: waste lard oil; animal waste oil biofuel; biofuel emissions

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1. Introduction

Biodiesel is a sustainable and environmentally friendly alternative fuel created from a variety of vegetable oils, animal fats, and waste oils. Because of its low cost and abundance, waste lard oil, also known as waste frying oil, is an important source of feedstock for biodiesel manufacturing [1]. Recent developments in renewable energy research have emphasized the importance of exploring alternative fuel sources to reduce greenhouse gas emissions and dependence on finite fossil fuel resources. Waste swine oil, a byproduct of the meat industry, represents a potential feedstock for biodiesel production, offering the dual benefits of waste management and biofuel production [2]. As stated in reports, a sizable amount of waste fat and oil is created each year. According to the National Renewable and Energy Laboratory, each individual produces around 2 L of fat, oil, and grease. Promoting the creation of biofuel from cooked waste oils is important for a number of reasons. The main justifications are the favorable public perception of clean biofuel production, control of land and water pollution, recycling of waste into useful products, decreases in offensive odors, and the avoiding of the food vs. fuel debate. Animal- and plant-cooked waste oils make more sustainable and profitable feedstock since they are less expensive [3].

Waste lard oil biodiesel has been demonstrated to function similarly to normal diesel fuel while emitting less greenhouse gases [2]. Although biodiesel offers several advantages, it is critical to investigate its emissions in order to determine their influences on air quality and public health. Previous research has shown that biodiesel can reduce certain emissions, such as carbon monoxide and hydrocarbons, while increasing others, such as nitrogen oxides and particulate matter, depending on the feedstock and engine settings [4]. Understanding the emissions profile of biodiesel from waste lard oil can give policymakers, engine manufacturers, and consumers useful information about its possible environmental and health consequences.

Biodiesel, derived from plant and animal fats, offers a promising solution due to its lower carbon footprint and compatibility with existing diesel engines [5]. As an alternative to edible and non-edible feedstocks, biofuel, produced from cooking waste fats and vegetable oils produced by food processing plants, restaurants, and home outlets, has been utilized [6]. With the increased usage of biodiesel, contaminants and mobile carcinogens can be reduced. For the manufacturing of biodiesel, a variety of feedstocks including vegetable oils, algal oils, animal fats, microbial oils, and waste oils can be employed.

The processes for producing biodiesel include transesterification, pyrolysis, and the supercritical fluid technique among others. The most popular technique of producing biodiesel out of all of them is transesterification, which yields glycerol and biodiesel as byproducts from the oil [6–8]. While prior research has explored the emission characteristics of biodiesel blends using different feedstocks, there is a need for further investigation specifically focusing on waste swine oil biodiesel blends. This study fills this research gap by examining the impact of biodiesel blending on emission characteristics, specifically targeting carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM) emissions.

The major goal of this research is to look at the emissions characteristics of a one-cylinder engine powered by waste lard oil biodiesel. This study specifically intends to:

1. Measure the emissions of nitrogen oxides, particulate matter, carbon monoxide, and hydrocarbons from an engine running on waste lard oil biodiesel at various engine loads and speeds.
2. Contrast the emissions of an engine running on waste lard oil biodiesel with those of a standard diesel engine.
3. Examine the influence of engine load and speed on the emissions of a waste lard oil biodiesel-powered engine.

The significance of this research lies in its contribution to the understanding of the environmental impact and viability of waste swine oil biodiesel blends. The findings have implications for waste management strategies, the reduction of greenhouse gas emissions, and the development of sustainable energy sources. The outcomes of this study can inform policy-making decisions and facilitate the transition to a greener and more sustainable energy future.

2. Literature Review

Biodiesel is a renewable and sustainable fuel that may be made from a variety of sources, including lard oil waste. Several studies have been conducted to study biodiesel's performance and emissions properties derived from used lard oil in engines. Cengiz et al. (2009) investigated a diesel engine's combustion parameters and emissions powered by biodiesel derived from waste lard oil. They discovered that biodiesel made from waste lard oil emits less particulate matter (PM), hydrocarbon (HC), and carbon monoxide (CO) than diesel fuel. However, in their study, the usage of biodiesel raised nitrogen oxide (NOx) emissions slightly [9].

Similarly, A P Sathiyagnanam et al. (2012) investigated the performance and emissions of a diesel engine powered by biodiesel derived from waste lard oil. They discovered that using biodiesel resulted in decreased HC and CO emissions but increased NOx emissions when compared to diesel fuel [10]. Santana et al. (2021) found an increase in PM emissions when utilizing biodiesel derived from waste lard oil, but no significant difference in NOx emissions [11].

Furthermore, Srinivasan et al. (2022) evaluated the impacts of waste lard oil biodiesel on engine performance and emissions in a single-cylinder diesel engine. They discovered that using biodiesel resulted in reduced HC and CO emissions but greater NOx emissions than diesel fuel [12].

Madhu et al. (2022) investigated the emissions characteristics of a diesel engine running on biodiesel derived from waste lard oil at varying engine loads and speeds. They discovered that using biodiesel resulted in greater PM emissions than diesel fuel, especially at low engine loads and speeds. They did, however, detect fewer CO_2 emissions when using biodiesel [13].

2.1. Effects of Biodiesel on Engine Emissions

Biodiesel is a renewable and sustainable alternative to traditional diesel fuel that may be made from a variety of sources including used cooking oils and animal fats. It is gaining popularity as a potential remedy to the harmful environmental effects of diesel fuel consumption. Several studies have been conducted to evaluate the effects of biodiesel on engine emissions, with an emphasis on PM, HC, CO, and NOx emissions.

One of the primary benefits of biodiesel is that it emits less particulate matter than diesel fuel. This is owing to its increased oxygen concentration, which results in more complete combustion and less PM generation [1]. Cengiz et al. (2009) discovered that using biodiesel instead of diesel fuel resulted in considerably decreased PM emissions in research on the combustion characteristics and emissions of a diesel engine powered with biodiesel from waste lard oil [9].

According to Santana et al. (2021), biodiesel has fewer HC and CO emissions than diesel fuel. The decreased HC and CO emissions can be ascribed to biodiesel's oxygen content, which allows for more thorough combustion. However, when using lesser-grade biodiesel or under particular engine operating circumstances, the reduction in HC and CO emissions may be less substantial.

Biodiesel, on the other hand, may produce more NOx emissions than diesel fuel. This is owing to the greater combustion temperature and oxygen concentration when using it, both of which boost NOx generation. However, by applying correct engine calibration and after-treatment technologies like exhaust gas recirculation and selective catalytic reduction, NOx emissions may be reduced [10,11].

Biodiesel's impact on engine performance has been examined in addition to its impacts on engine emissions. Researchers discovered that using biodiesel may result in reduced engine power and torque when compared to diesel fuel, perhaps due to its lower energy density and greater viscosity. However, the drop in engine power and torque may be mitigated by biodiesel's higher fuel economy, as found in multiple experiments [13].

It is important to note that the effects of biodiesel on engine emissions and performance might differ based on the source and quality of the biodiesel in question as well as the engine operating circumstances. Biodiesel made from waste lard oil, for example, may have different qualities and combustion characteristics than biodiesel made from other sources such as soybean or rapeseed oil. Engine operating parameters, like engine load and speed, also have substantial impacts on biodiesel emissions and performance.

2.2. Knowledge Gaps and Research Needs

Despite the expanding body of literature on the use of biodiesel derived from used lard oil in engines, there are significant knowledge gaps and research requirements in this subject. One major area of research is optimizing engine operating conditions to reduce biodiesel's negative influence on NOx emissions while preserving its favorable impact on PM, HC, and CO emissions. Another area of investigation is the development of more efficient and cost-effective ways for producing biodiesel from waste lard oil, which can aid in its widespread usage as a renewable fuel.

Furthermore, more study is required to assess the long-term durability and dependability of engines powered by waste lard oil biodiesel. This is especially critical since biodiesel has the potential to generate engine deposits and corrosion, which can lead to lower engine performance and dependability over time.

The source and quality of biodiesel must be considered since they might have major impacts on its emissions performance. Biodiesel made from waste lard oil, for example, has been shown to have different impacts on engine emissions. As previously stated, Sathiyagnanam et al. (2018) discovered that using biodiesel derived from waste lard oil resulted in decreased PM, HC, and CO emissions when compared to diesel fuel, but slightly higher NOx emissions. However, Santana et al. (2021) found that using biodiesel derived from waste lard oil resulted in greater NOx emissions, whereas Cengiz et al. (2009) discovered an increase in PM emissions.

Aside from the supply and quality of biodiesel, engine operating circumstances might have impacts on emissions performance. High engine loads and speeds, for example, have been observed to result in greater NOx emissions with biodiesel than with diesel fuel [14]. Low engine loads and speeds, on the other hand, have been observed to result in decreased NOx emissions when using biodiesel (Ashok et al., 2019). This implies that the ideal operating parameters for biodiesel engines may differ from those for diesel engines [15].

3. Methodology

3.1. Experimental Setup and Materials

Figure 1 depicts the experimental setup for a single-cylinder, water-cooled farm diesel engine with a rated power output of 7.4 kW. Daedong Korea Ltd. (Daegu Gwangyeoksi, Republic of Korea) supplied the diesel engine with indirect injection. Experiments were carried out with a constant load and varied speeds of 1200, 1400, 1600, and 1800 rpm. Table 1 lists various engine characteristics and information points. The engine's power output was measured using an eddy-current dynamometer.

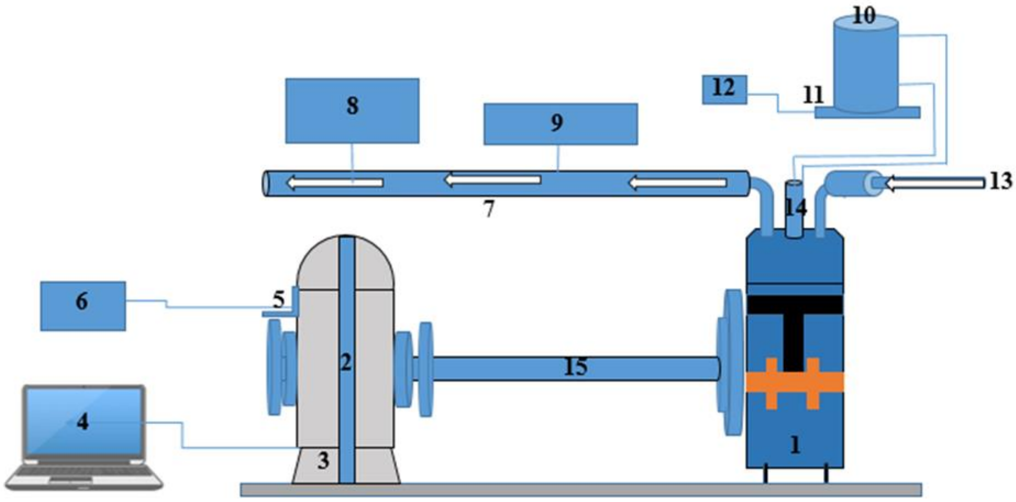

Figure 1. Experimental setup: (1) Single-cylinder engine indirect ignition, (2) eddy-current dynamometer, (3) load cell for torque, (4) torque measurement, (5) RPM sensor, (6) RPM display, (7) exhaust pipe, (8) gas emission analyzer, (9) smoke analyzer, (10) fuel tank, (11) load cell for fuel weight, (12) fuel weight display, (13) air intake, (14) injector, (15) propeller shaft.

Table 1. Engine specification.

Parameters	Description
Engine type	Horizontal, 4-stroke
Manufacturer	Daedong Korea Ltd.
Rated Power Output (kW)	7.4
Engine cooling	Water-cooled
Number of cylinders	1
Stroke length (mm)	95
Bore (mm)	95
Compression Ratio	21
Displacement (cc)	673
Injection pressure (kg/cm^{-2})	200

The variations in engine performance characteristics were measured using BTE and BSFC. A gas analyzer (CGA-4500) from the Republic of Korea was used to examine engine emission parameters. The analyzer utilizes non-dispersive infrared (NDIR) technology for measuring carbon monoxide (CO) concentrations in the range of 0.00 to 10.00%. It also employs NDIR for quantifying carbon dioxide (CO_2) levels from 0.0 to 20.0%. The analyzer's hydrocarbon (HC) measurement capability covers a range of 0 to 10,000 ppm, while oxygen (O2) levels are detected using an electrochemical sensor in the range of 0.00 to 25.00%. Lastly, nitric oxide (NO) concentrations in the range of 0 to 5000 ppm are determined using an electrochemical sensor. A probe was inserted into the exhaust pipe to gather digital emission data. A smoke meter was used to measure the engine's smoke. A k-type thermocouple was used to monitor the temperature of the exhaust gas.

The initial phase of data collection involved operating the engine using pure diesel fuel. To ensure standardized conditions, the engine was driven for 10 min prior to conducting all tests. The engine was subjected to a constant load of 50% and operated at engine speeds of 1200, 1400, 1600, and 1800 rpm. During the tests, the temperature of the lubricating oil was maintained within the range of 85 to 90 °C. The engine was run for a duration of 15 min while being monitored and recorded.

Uncertainty has been assessed to decrease the parapraxis in the data. Calibration of the equipment is critical for collecting correct results during experimentation. Readings were taken more than twice during the experiment to ensure accuracy, and the arithmetic mean was calculated. Table 2 shows the range and resolution of the smoke meter and gas analyzer.

Table 2. Measuring range and precision of smoke meter and gas analyzer.

Exhaust Emission	Range	Resolution	Accuracy and Uncertainties
CO	0.00–10.00	%	±0.01%
HC	0–10,000	ppm	±1 ppm
CO_2	0.0–20.0	%	±0.1%
O_2	0.00–25.00	%	±0.1%
NO_x	0–5000	ppm	±1 ppm
Smoke	0–100	%	±0.05%
Thermocouple (K-Type)	0–1200	°C	±0.1 °C

3.2. Fuel Preparation

The initial step in the process is the collection of waste lard oil from BBQ restaurants. As waste swine oil is a byproduct generated during cooking processes, BBQ restaurants often have surplus quantities available. By establishing an agreement with the restaurants, the waste lard oil can be obtained at no cost. The waste lard oil is typically collected in a condensed form, stored in containers or drums.

Once the waste swine oil is obtained, the filtration process begins. To remove any food and meat residues present in the oil, a gas range is used as heating equipment. The waste lard oil is heated on the gas range, causing it to melt and become more fluid. As the oil heats up, the food and meat remain separate from the oil and can be easily skimmed off or filtered out. The Figure 2 shows the step which is crucial to ensure that impurities and solid particles are eliminated from the waste swine oil.

During the heating and filtration process, the temperature has to be carefully monitored to avoid overheating or degradation of the oil. The filtered waste lard oil, free from food and meat residues, is then collected for further processing to convert it into biodiesel. It is important to note that this process focuses on the initial steps of waste lard oil collection and filtration. Subsequent steps, such as transesterification to convert the filtered waste lard oil into biodiesel, may be necessary to complete the biodiesel production process. These additional steps typically involve chemical reactions and purification processes to obtain a fuel-grade biodiesel product.

Figure 2. Filtration process of waste lard oil.

In the university lab, biodiesel is prepared using the transesterification process. A sample of 500 mL waste swine oil is taken in a beaker and heated to 30 °C to reduce its viscosity and facilitate filtration. The preparation of biodiesel involves using methanol alcohol (99.9% purity) and potassium hydroxide catalyst (reagent grade 90%, flakes) obtained from Sigma Aldrich, Republic of Korea. The waste swine oil is mixed with a liquid solution of methanol (135 mL) and potassium hydroxide (2.5 gm) in a 10:1 molar ratio. The mixture is heated to 55 °C for 2 h at a constant speed of 700 rpm. After the reaction, the product is allowed to settle overnight to separate the ester phase (biodiesel) from the glycerol phase.

The glycerol is separated using a separating funnel, while the biodiesel is poured into a gravity separator for 24 h to further separate impurities. The biodiesel is then purified using the water-washing method. Distilled water, heated to 70 °C, is added to the biodiesel in the gravity separator, and the mixture is shaken thoroughly before allowing the layers to separate. This washing process is repeated 3–4 times to remove glycerol and residual by-products.

To remove water content and residual methanol, the biodiesel is heated to above 100 °C after the washing process. This step is crucial to enhance engine performance as water contents in biodiesel can affect combustion. The resulting biodiesel volume obtained is 320 mL, and the entire process is repeated to produce additional biodiesel.

The described methodology outlines the various steps involved in the preparation of biodiesel from waste swine oil including filtration, transesterification, settling, separation, purification, and removal of water and methanol. These steps are essential to ensure the production of high-quality biodiesel that meets the necessary standards and is suitable for use in combustion engines.

3.3. Properties of Biodiesel

Table 3 shows the fuel properties and ASTM standards of the waste swine oil biodiesel and diesel used in the experiment. When comparing waste swine oil biodiesel to conventional diesel fuel, there are several notable differences in their properties, as listed below:

Table 3. Fuel properties and ASTM standards.

Property	ASTM Standard	Diesel	Lard biodiesel	B20	B40	B60	B80
Density (kg/m^3)	800–880	820	816	821	833	841	859
Viscosity at 40 °C (cSt)	1.9–6	2.87	4.63	2.62	3.81	4.99	6.17
Flash Point (°C)	>130	58	88	85	89	95	103
Cetane Number	48–65	48.7	65	52	58	62	65
Calorific Value (Mj/kg)	>35	45.51	40.21	44.18	43.95	41.76	40.35

1. Viscosity: Waste swine oil biodiesel typically has higher viscosity compared to petrodiesel. This can affect its flow characteristics and may require engine modifications for proper combustion.

2. Density: Waste swine oil biodiesel generally has a slightly higher density than petrodiesel. Density affects the energy content of the fuel and can impact fuel consumption rates.

3. Calorific value: Waste swine oil biodiesel has a slightly lower calorific value than petrodiesel. The calorific value represents the energy released during combustion and can affect engine performance and efficiency.

4. Cetane number: Waste swine oil biodiesel's cetane number indicates its ignition quality. Higher cetane numbers are associated with better combustion characteristics and smoother engine operation.

5. Oxidation stability: Waste swine oil biodiesel tends to have lower oxidation stability compared to petrodiesel. Oxidation stability refers to a fuel's ability to resist degradation when exposed to oxygen, which can affect fuel storage and shelf life.

6. Lubricity: Waste swine oil biodiesel generally exhibits improved lubricity compared to petrodiesel. This property helps reduce friction within the fuel system, contributing to engine longevity.

4. Results

4.1. Emission Characteristics

4.1.1. Variation of Particulate Matter (PM) Compound with Engine Speed

It can be observed from Figure 3 that as the amount of biodiesel mix increases, PM emissions tend to decrease at all engine speeds. For example, at 50% engine load and 1800 rpm, the PM emissions for B0/PM, B20/PM, B40/PM, B60/PM, and B80/PM are 25, 21, 15, 6, and 4, respectively. This tendency is consistent with prior research, which has demonstrated that using biodiesel can lower PM emissions due to its higher oxygen content and superior combustion qualities [16].

It can be seen that when the engine speed increases, the PM emissions tend to decrease at all biodiesel mix percentages. At 50% engine load and 80% biodiesel mix (B80/PM), for example, PM emissions drop from 26 at 1200 rpm to 17 at 1600 rpm. This trend is most likely due to the improved mixing of fuel and air at higher engine speeds, resulting in more complete combustion and fewer PM emissions [17].

It is important to note that the variations in PM emissions between the three biodiesel mixes are less noticeable at low engine speeds (e.g., 1200 rpm). PM emissions are 33 at 1200 rpm and 28 at 1400 rpm with 50% engine load and 20% biodiesel mix (B20/PM). This shows that the advantages of utilizing biodiesel blends may be greater at higher engine speeds.

The fact that B80/PM had lower PM emissions than B60/PM in the study is in line with earlier research that demonstrated that the lowering of PM emissions may be achieved by increasing the proportion of biodiesel in diesel blends. This is due to the fact that biodiesel contains more oxygen than petroleum diesel, which might result in more complete combustion and lower PM emissions [18]. For instance, a study by Agarwal et al. (2015) showed that utilizing a B84 blend of biodiesel in a diesel engine decreased PM emissions when compared to using pure diesel fuel [19].

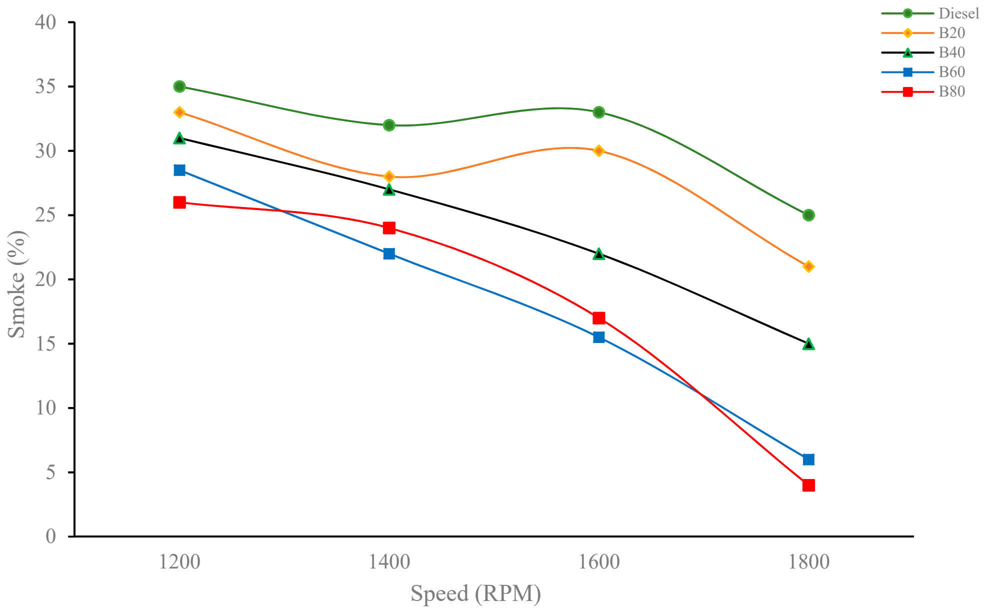

Figure 3. PM emissions of various blends at different RPMs.

4.1.2. Variation of NO_X Emissions with Engine Speed

The data in Figure 4 indicate the NOx emissions for various biodiesel blend percentages (B0, B20, B40, B60, and B80) at four different engine speeds (1200, 1400, 1600, and 1800 rpm) and 50% engine load. According to the findings, increasing the proportion of biodiesel in diesel blends might result in increased NOx emissions. The NOx emissions for B80/NOx and B60/NOx at 50% engine load at 1800 rpm are 416 and 395, respectively.

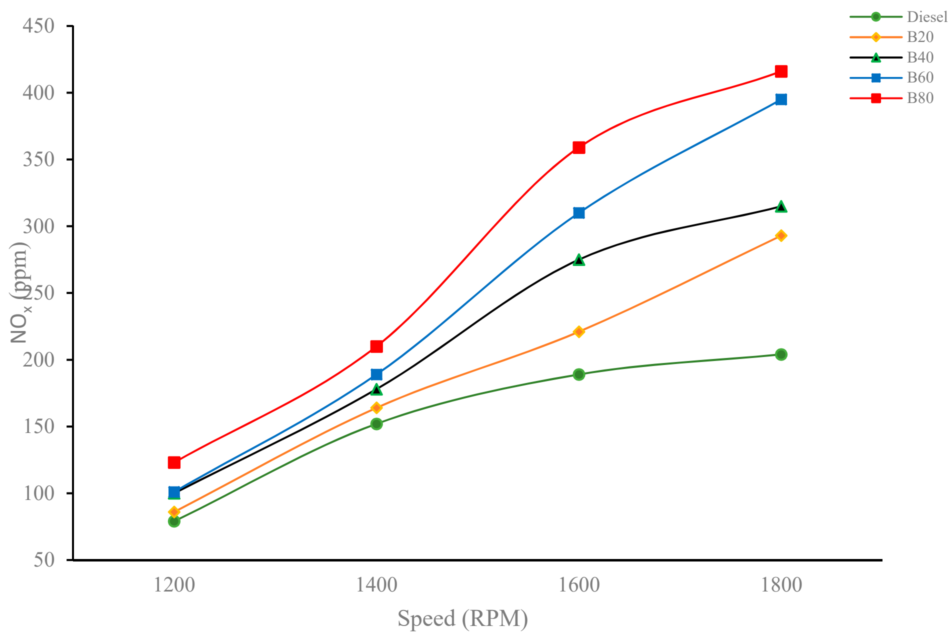

Figure 4. NOx emissions of various blends at different RPMs.

These findings align with earlier research that found increases in NOx emissions when biodiesel mixes were used. This increase in NOx emissions is due to biodiesel's greater oxygen content, which can result in more complete combustion and higher combustion temperatures, resulting in higher NOx emissions [20]. Mandal et al. (2021), for example, conducted an experimental investigation on the combustion and emission characteristics of a diesel engine fueled by various biodiesel mixes. According to the study, utilizing a B20 biodiesel blend resulted in a 30% increase in NOx emissions when compared to pure diesel fuel [16].

The increased NOx emissions for B80/NOx compared to B60/NOx might be attributed to B80's higher oxygen concentration, which can result in more complete combustion and higher combustion temperatures. Furthermore, the physical and chemical qualities of biodiesel blends might influence NOx emissions. B80, for example, may have a higher cetane number than B60, indicating improved ignition quality and perhaps greater combustion temperatures and higher NOx emissions.

4.1.3. Variation of HC Emissions with Engine Speed

Figure 5 reveals that as engine speed increases, hydrocarbon (HC) emissions decrease across the board for all biodiesel mixes. This is most likely due to the greater atomization and vaporization of fuel droplets at higher engine speeds, resulting in better combustion and small quantity of unburned hydrocarbons [16,21]. The reductions in HC emissions with increased engine speed, on the other hand, are not similar across all biodiesel mixes. At 50% engine load, for example, B80/HC has the maximum reduction (of 53%) between 1200 and 1800 rpm, while B20/HC has the lowest reduction (of 32%). This implies that the best engine speed for lowering HC emissions may differ depending on the biodiesel blend. In terms of biodiesel mixes, research shows that increasing the amount of biodiesel in a blend reduces HC emissions. This is most likely due to biodiesel's high oxygen content, which promotes the more thorough combustion of the fuel and minimizes unburned hydrocarbon emissions [21].

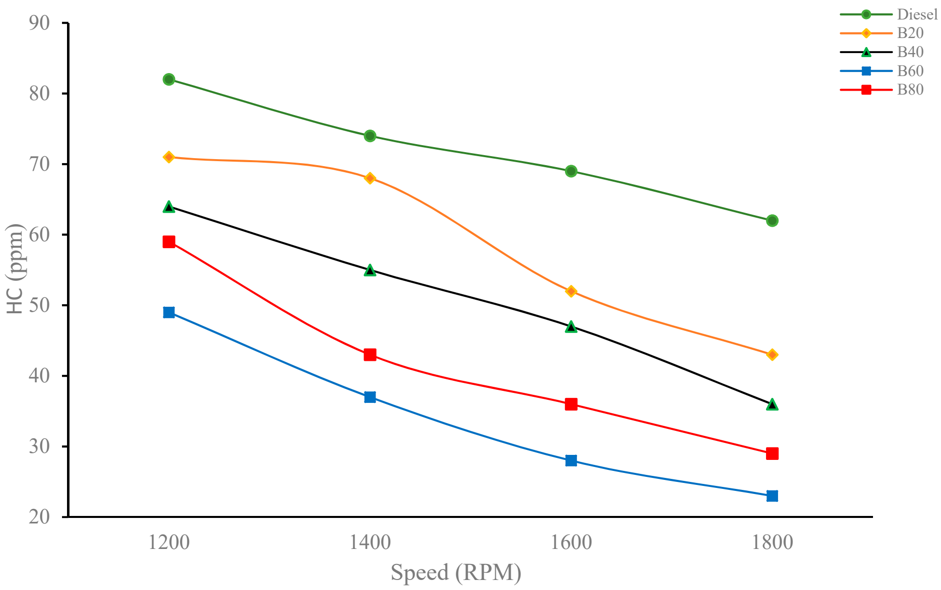

Figure 5. HC emissions of various blends at different RPMs.

However, the effect of biodiesel blend on HC emissions varies depending on engine speeds and loads. For example, at 1400 rpm and 50% engine load, B40/HC emits more HC than B20/HC, implying that the proportion of biodiesel in the mix may impair combustion efficiency.

These findings show that biodiesel from waste lard oil can help reduce HC emissions in diesel engines, and additional study is needed to establish the ideal mix and engine settings for lowering emissions while improving engine performance.

4.1.4. Variation of CO Emissions with Engine Speed

Figure 6 illustrates the CO emissions for various biodiesel blend percentages (B0, B20, B40, B60, and B80) at four different engine speeds (1200, 1400, 1600, and 1800 rpm) with 50% engine load. The amounts of CO emitted are measured in parts per million (ppm).

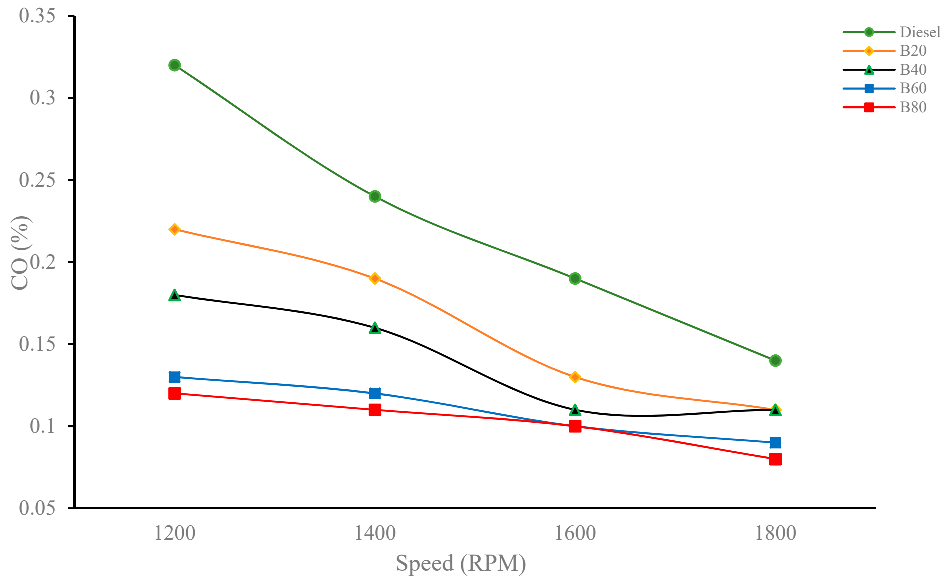

Figure 6. CO emissions of various blends at different RPMs.

Firstly, as the amount of biodiesel mix grows, CO emissions fall at all engine speeds. At 1800 rpm, the CO emissions for B0/CO, B20/CO, B40/CO, B60/CO, and B80/CO are 0.32 ppm, 0.22 ppm, 0.18 ppm, 0.13 ppm, and 0.12 ppm, respectively. This tendency is consistent with prior research, which has demonstrated that using biodiesel can lower CO emissions due to its higher oxygen content and improved combustion qualities.

Secondly, engine speed has a substantial influence on CO emissions. CO emissions tend to rise at higher engine speeds, independent of the proportion of biodiesel blend utilized. At 50% engine load and 80% biodiesel blend (B80/CO), for example, CO emissions rise from 0.08 ppm at 1200 rpm to 0.12 ppm at 1800 rpm. This is most likely owing to incomplete combustion at faster speeds, which might result in increased CO levels. Vikas Sharma et al. found that waste cooking oil biodiesel resulted in higher CO emissions due to its higher density, which increased fuel mass per stroke and limited oxidation time. Fuel properties like density and viscosity also affected CO formation, with higher viscosity impacting spray penetration and atomization, leading to larger fuel droplet sizes and incomplete combustion and thus increasing CO emissions [22].

It is also important to note that the variations in CO emissions across the three biodiesel mixes are less noticeable at low engine speeds (e.g., 1200 rpm). CO emissions are 0.11 ppm at 1200 rpm and 0.19 ppm at 1800 rpm with 50% engine load and 20% biodiesel mix (B20/CO). This shows that the advantages of utilizing biodiesel blends may be greater at higher engine speeds.

4.1.5. Variation of CO_2 Emissions with Engine Speed

Figure 7 depicts the emission characteristics of a waste swine biodiesel on a one-cylinder engine at 50% load. One of the most important findings is that CO_2 emissions rise with increasing percentages of biodiesel from B20 to B80. CO_2 emissions reach a high of 5.1 at B40 and then decline somewhat (to 6) at B60. The engine's RPM increases as the proportion of biodiesel increases. It seems that CO_2 emissions are slightly lower at B80 than at B20, which might be ascribed to better combustion efficiency. The same result was obtained by Janarthanam H et al. in their research on a single-cylinder diesel engine. It was observed that the emission of carbon dioxide (CO_2) rises in correlation with higher compression ratios. This can be attributed to the improved combustion and better blending of fuel and air at elevated compression ratios. Additionally, as the engine load increases, the quantity of CO_2 emissions also rises. This is due to the combustion temperature increasing with higher loads, facilitating complete fuel combustion. The increased temperature also ensures an adequate supply of oxygen to convert carbon monoxide (CO) to carbon dioxide (CO_2), leading to an overall increase in CO_2 emissions [23].

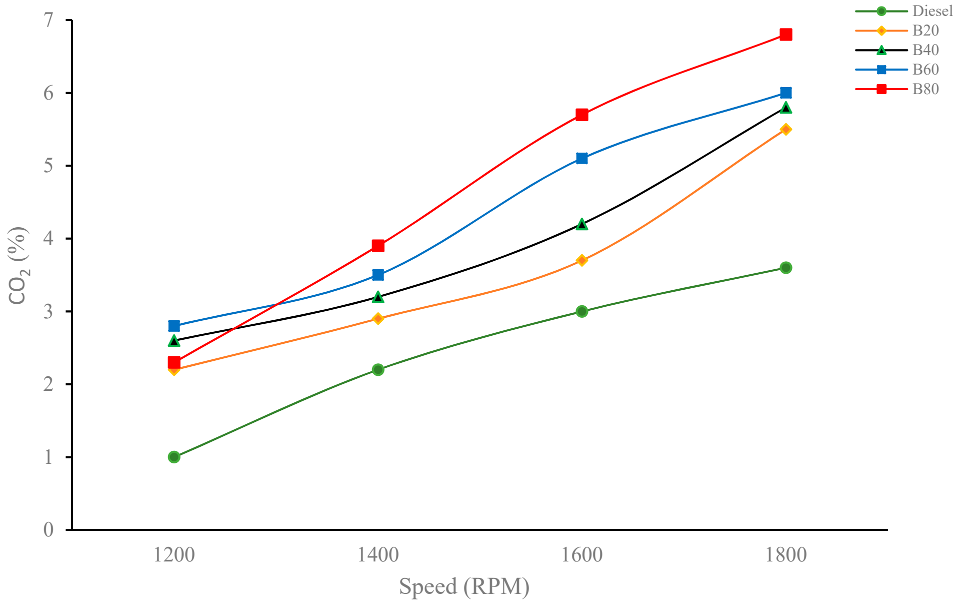

Figure 7. CO_2 emissions of various blends at different RPMs.

4.2. Performance Characteristics

Effects on Brake Thermal Efficiency

An engine's capacity to transfer the chemical energy of fuel into productive activity is measured by brake thermal efficiency (BTE). Figure 8 illustrates that the BTE lowers as the proportion of biodiesel in a fuel blend increases. At 50% load, the BTE values for B0 to B80 vary from 22.21% to 25.94%. This drop in BTE is most likely due to biodiesel's higher viscosity and lower calorific value compared to diesel fuel, which results in incomplete combustion and decreased engine efficiency.

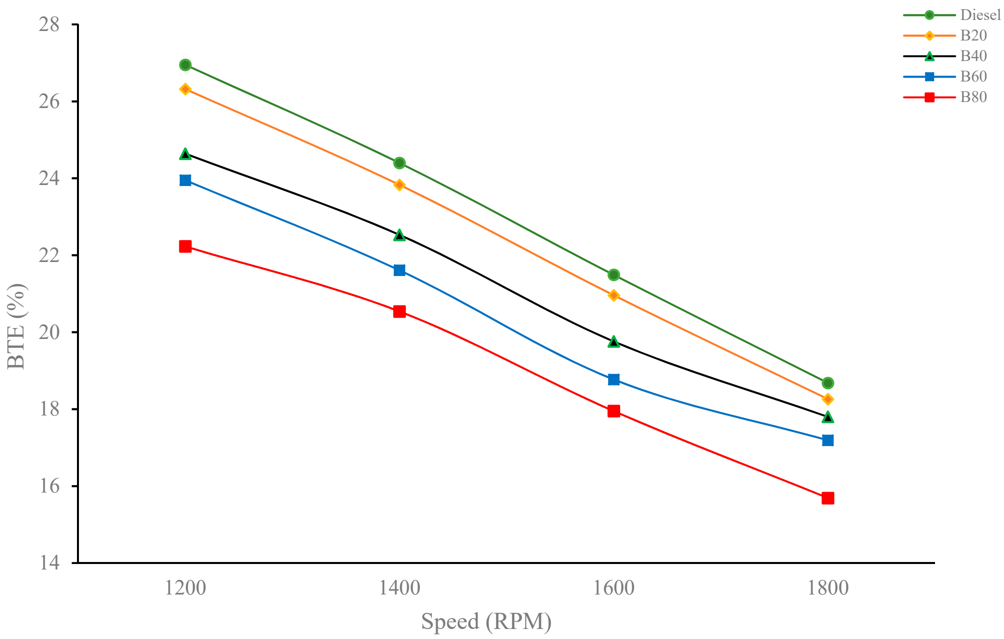

Figure 8. BTE values of different blends at different RPMs.

The decrease in BTE as biodiesel concentration increases is consistent with earlier research on the usage of biodiesel in diesel engines (Hussain et al., 2017) [24]. These investigations found that as biodiesel concentration increased, BTE decreased owing to reasons such as shorter fuel injection time, lower heating value, and worse combustion efficiency.

5. Conclusions

1. Increasing the fraction of biodiesel in diesel blends can reduce PM emissions significantly, with PM emissions dropping as the percentage of biodiesel in a fuel mix increases.
2. Increasing engine speed reduces HC emissions in all biodiesel mixes by improving fuel atomization and vaporization.
3. Biodiesel mixes may provide greater benefits at higher engine speeds, with the most visible improvements occurring at above 1800 rpm.
4. As the percentage of biodiesel blend increases, CO emissions fall at all engine speeds, with the most notable variations noted at 1800 rpm.
5. The amount of biodiesel in a mix might affect NOx emissions, with higher biodiesel content potentially resulting in higher NOx emissions due to the higher oxygen content of biodiesel.
6. The BTE of waste lard biodiesel decreases with an increasing biodiesel proportion in a fuel mix, most likely due to biodiesel's higher viscosity and lower calorific value compared to diesel fuel.

Finally, the statistics suggest that employing a biodiesel blend in a diesel engine may significantly reduce PM emissions. Due to biodiesel's greater oxygen content, viscosity, and lower calorific value compared to diesel fuel, increasing the amount of biodiesel in a mix may result in higher NOx emissions and lower BTE. Engine speed also has an impact on emissions, with greater speeds resulting in higher CO and NOx emissions but lower HC emissions. The best blend and engine settings for biodiesel use require additional investigation in order to increase engine performance and reduce emissions.

In conclusion, this study on the impact of biodiesel blending using waste swine oil as a feedstock has provided valuable insights. To further advance our understanding, future research directions include expanding the sample size to encompass engines of varying sizes and types, assessing long-term effects on engine performance and emissions, exploring different waste animal oil feedstocks and pre-processing methods, and conducting a lifecycle assessment to evaluate overall environmental impact. Addressing these areas of investigation will enhance our knowledge of emission characteristics, engine performance, and environmental sustainability, facilitating the adoption of biodiesel blends and supporting the transition to a greener future.

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Nomenclature

PPM	Parts Per Million
RPM	Revolutions Per Minute
CI	Compression Ignition
IC	Internal Combustion
BP	Brake Power
KOH	Potassium Hydroxide
NaOH	Sodium Hydroxide
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
EGR	Exhaust Gas Recirculation
CO	Carbon Monoxide
CO_2	Carbon Dioxide
HC	Hydrocarbon
NO_X	Nitrogen Oxide

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