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Article

Experimental Study on the Performance and Emission Characteristics of the Diesel Engine Fueled with Tung Oil-Based Biodiesel Blends

Zhiyue Mu [a], Jianqin Fu [c], Feng Zhou [a,b,*], Kainan Yuan [b,*], Juan Yu [a], Dan Huang [a], Zhuangping Cui [b] and Jingping Liu [c]

[a] College of Mechanical and Electrical Engineering, Central South University of Forestry and Technology, Changsha 410004, China
[b] China Machinery International Engineering Design & Research Institute Co., Ltd, Changsha 410000, China
[c] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China

Abstract: In this paper, the performance and emission characteristics of the engine were investigated with varying ratios of tung oil-based biodiesel blends (B10, B20, and B50) and 0# diesel under different operating conditions. The experimental results indicated that both the power and torque of B10 increased compared with 0# diesel, which increased by 1.9% and 6.6%. But the power and torque of B20 and B50 decreased slightly. The fuel consumption rate increased slightly with an increasing percentage of biodiesel added. In general, the overall emissions of tung oil-based biodiesel blends were lower compared to 0# diesel. Compared to 0# diesel, the CO-specific emissions of B10 decreased by 42.86% at medium and large load, and NO_x-specific emissions of tung oil-based biodiesel blends were reduced at all load conditions, except for B50. In addition, HC-specific emissions were all reduced, especially for B20 decreased by 27.54% at 50% load. With the increase of the biodiesel blend ratio, the smoke decreased significantly. Among the blends tested, B50 showed the greatest reduction of 38.05% at 2000 rpm. Overall, it can be asserted that using biodiesel presents a favorable alternative fuel option that can lead to a more environmentally friendly exhaust output.

Keywords: biodiesel; tung oil; diesel engine; performance; exhaust emissions

1. Introduction

As car ownership in China continues to rise rapidly, automobile exhaust emissions of harmful substances like CO, NO_x, and PM have become the primary source of urban air pollution, posing significant threats to human health. As we strive to enhance the quality of life and boost prosperity, one of the most significant challenges is meeting the ever-increasing demand for energy. Despite ongoing efforts to transition to alternative energy sources, it is apparent that fossil fuel-based internal combustion engines (ICEs) will remain the primary power source for energy and transportation in the foreseeable future. [1–3]. However, as concerns about global environmental deterioration grow, the exhaust emissions from ICEs, such as carbon monoxide (CO), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and hydrocarbons (HC) are increasingly subject to stringent regulations [4–6]. In order to promote the use of alternative fuels and address environmental concerns, major advanced and emerging economies have carried out a series of regulations [7–9]. As a green and environmentally friendly oxygenated fuel, biodiesel can effectively reduce the CO, NO_x, and PM emissions of diesel engines. In addition, it can curb the increasing trend of automobile emission pollution as soon as possible, and significantly improve the air quality of cities in China. Because of this, biodiesel has attracted more and more attention from scholars.

Biofuel is a newly developed fuel derived from biological materials that can exist in solid, liquid, and gaseous forms. As a promising renewable energy source, biodiesel offers excellent environmental

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protection characteristics such as good cold start and lubrication performance, reduced greenhouse gas emissions, and potential opportunities for sustainable economic growth [10]. On the other hand, it is essential to consider the physicochemical properties of biodiesel, given its unique composition and properties. The higher kinematic viscosity of biodiesel improves the combustion quality of fuel [11,12], and the higher flash point makes the storage, treatment and transportation safer [13-15]. The cetane number (CN) influences the ignition quality of the fuel and is a measure of the ignition timing in the combustion chamber [16]. Overall, biodiesel has higher CN than pure diesel. Higher CN usually indicates a shorter ignition delay and earlier combustion, which is conducive to the smooth operation of the engine [17,18]. The biodegradability and low toxicity of plant biofuels have rendered them a desirable and practical substitute for diesel fuel. [19,20].

Based on the above, biodiesel can play a significant role in reducing environmental pollution, leading countries worldwide to explore oils with suitable properties for producing biodiesel. Among the many options, the Tung tree is a valuable woody oil tree species in China [21]. Known for its high seed oil content, it is considered one of the four major woody oil tree species. Tung oil, also known as "China wood oil" [22], is extracted by pressing the seeds of the tung tree [23]. China tung tree species not only have a variety, but also high yield, and good oil quality, the oil content of absolute dried tung seed is more than 50%, and the oil content of absolute dried tung kernel can be as high as 68%. In the context of the country's vigorous biomass energy development, biodiesel preparation from tung oil has great practical significance in today's increasing energy shortage. The high value and wide use of tung oil have attracted the attention of many countries. Its special chemical structure and active chemical properties have aroused the interest of many chemists who are committed to the study of tung oil chemistry.

The performance and emission characteristics of an engine fueled with biodiesel have been the subject of extensive research by scholars and experts alike. Researchers have investigated the combustion performance of various types of biodiesel fuels, seeking to identify potential benefits and limitations. Ahmad Muhsin Ithnin et al. [24] studied the combustion performance and emission analysis of diesel engines fueled with low-grade diesel emulsified fuel. And they found that the W / D formed from low-grade diesel is a potential alternative fuel, which could result in greener exhaust emissions and reduced fuel use without worsening its performance. Osmano Souza Valente et al. [25] investigated the fuel consumption and emissions of diesel generators fueled with soybean biodiesel and castor oil. The results showed that the specific fuel consumption increased with the increase of biodiesel content in the fuel. Compared with diesel, biodiesel blends showed higher carbon dioxide emissions at low loads and lower carbon dioxide emissions at high loads. HC emissions were usually higher. The research conducted by Özer Can [26] examines the exhaust emissions, combustion characteristics, and performance of a diesel engine that utilizes blends of biodiesel derived from waste oil. The results indicated that with the increase of biodiesel, NO_x emissions increased by 8.7%, while smoke emissions decreased, and CO_2 emissions increased slightly.

The feasibility of biodiesel production from tung oil was studied by Ji-Yeon Park et al. [27]. When methanol and tung oil were mixed at the optimum molar ratio, the acid value decreased. Despite the fact that eleostearic acid, the primary constituent of tung oil, resulted in low oxidation stability as determined by the Rancimat method, the cold filter plugging point (CFPP) was satisfactory. Qiong Shang et al. [28] studied the chemical properties of tung oil biodiesel and its mixture with $0^{\#}$ diesel were studied. The effect of transesterification temperature on the performance of tung oil-based biodiesel was studied. Biodiesel was produced by the transesterification of benzene oil with methanol. It was observed that the tung oil-based biodiesel exhibited a low CFPP of -19°C and a higher kinematic viscosity (KV) of 7.070 mm^2/s as per the property analysis. Moreover, an increase in acid value (AV), KV, and CFPP was noted with increasing storage time. Nevertheless, the stability of the tung oil-based biodiesel could be improved by blending it with $0^{\#}$ diesel, and a storage time of one month did not affect the ability of B20 or lower blends to meet the ASTM D7467 specification. Additionally, these blends were found to be more stable compared to pure tung oil biodiesel.

There are many studies on the combustion and emissions performance of different types of biological diesel, as well as a certain study of the feasibility and chemical properties of tung oil-based

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biological diesel. However, there is a lack of research on the emission characteristics of tung oil-based biodiesel. Based on this, the performance and emission characteristics of an engine fueled with tung oil-based biodiesel were studied in this paper. In the present experiment, an analysis of those was investigated using three different portions of tung oil-based biodiesel (10%, 20% and 50%) blended with 0# diesel on a test engine. The test of speed characteristic, load characteristic, exhaust smoke and exhaust gas pollutant emission were conducted on the test ZS1115 GM diesel engine. The results were studied and analyzed, and the potential for future use of tung oil-based biodiesel was explored. It provides a data support for promoting and applying biodiesel, environmental protection, and emission reduction.

2. Experiments

This section is a description of experimental testing, including the physicochemical properties of biodiesel, experimental apparatus, and experimental setup. In addition, a comprehensive account of the initial and boundary conditions for laboratory experiments is provided.

2.1. Preparation and properties of biodiesel

The biodiesel used in this experiment is produced by the transesterification method, which is one of the better and most widely used biodiesel production methods. The transesterification method refers to the method of synthesizing biodiesel by transesterification reaction using various oils and fats and short-chain alcohols as raw materials, acids, alkalis, enzymes, etc. as catalysts, or without using catalysts under supercritical conditions. A variety of low molecular weight alcohols can be used for transesterification reactions, such as methanol, ethanol, propanol, etc. However, the most commonly used is methanol because methanol is not only cheap but also its polarity, short carbon chain, can quickly react with fatty acid glycerides. In this paper, using tung oil as raw material and NaOH as the catalyst, biodiesel was prepared by transesterification reaction with methanol. The reaction equation is shown in Figure 1 [29].

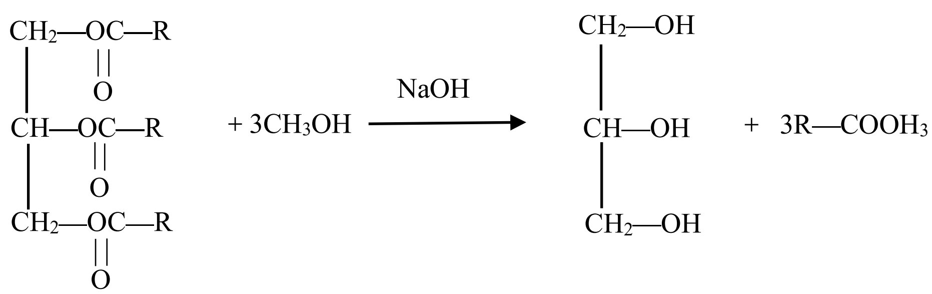

Figure 1. The synthesis scheme of transesterification for biodiesel production.

The main performance indexes and chemical and physical properties of tung oil-based biodiesel were compared with 0# diesel, as shown in Table 1. It shows the important characteristics of tung oil-based biodiesel and 0# diesel. The following characteristics of biodiesel and 0# diesel were determined according to the ASTM method.

Table 1. Comparison of the properties of biodiesel with 0# diesel.

Items	Target requirement	Biodiesel	0# diesel	Detection method
Density(20℃） $kg{\cdot}m^{-3}$	820-900	893	830	GB/T2540
Acidity/mg $KOH{\cdot}g^{-1}$	≤0.8	0.56	≤0.7	GB/T264
10% Steam residue charcoal / %	≤0.3	0.27	≤0.3	GB/T17144
Sulfated ash / %	≤0.020	0.012	—	GB/T2433
Mechanical impurities	None	None	—	GB/T511

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Water content / %	≤0.05	0.03	—	SH/T0246
Sulfur content / %	≤0.05	0.003	＜0.2	SH/T0689
Copper corrosion（50℃，3h）	≤1	1	1	GB/T5096
Kinematic viscosity(40℃) / $mm^2 \cdot s^{-1}$	1.9-6.0	5.02	3.0-8.0	GB/T265
Cold filter point/ ℃	≤0	-8.0	≤4	SH/T0248
Flashpoint/ ℃	≥130	140	≥60	GB/T261
Cetane number	≥49	56	≥49	GB/T386
90℃ Recovered temperature/ ℃	≤360	345	≤365	GB/T6536
Oxidation stability (110℃)/ h	≥6.0	6.5	—	EN14112
Free glycerol content/ %	≤0.02	0.01	—	ASTM D6584
Total glycerol content/ %	≤0.24	0.12	—	ASTM D6584
Calorific value/ $kJ \cdot g^{-1}$	—	38.96	45.4	—

2.2. Experimental setup and test engine

The test was carried out on a 14.71kW single-cylinder, four-stroke and air-cooled diesel engine. Table 2 is given the technical specifications of the engine in detail. Figure 2 is showed a schematic diagram of the experimental apparatus for diesel engines and instrumentation systems. To determine and measure the performance characteristics and pollutant emissions of biodiesel-fueled engine, diesel engines are equipped with the necessary measuring instruments. All instruments such as fuel consumption measuring device, exhaust gas analyzer, energy meter, ammeter, thermal load resistance, heat exchanger and digital thermometer are equipped on the engine bench.

Table 2. Main engine paraments.

Item	Content
Model	ZS1115GM
Number of Valves per Cylinder	4
Compression Ratio	17:1
Bore	115mm
Stroke	115mm
Engine Speed	2200rpm
Continuous output	14.71kW
Maximum output	16.18kW
Fuel consumption	≤244.8
Lubrication mode	Pressure and splash lubrication
Cooling method	Water-cooled evaporative
Starting mode	Electric starting
Appearance size (length ×width × height) (mm)	970×463×699

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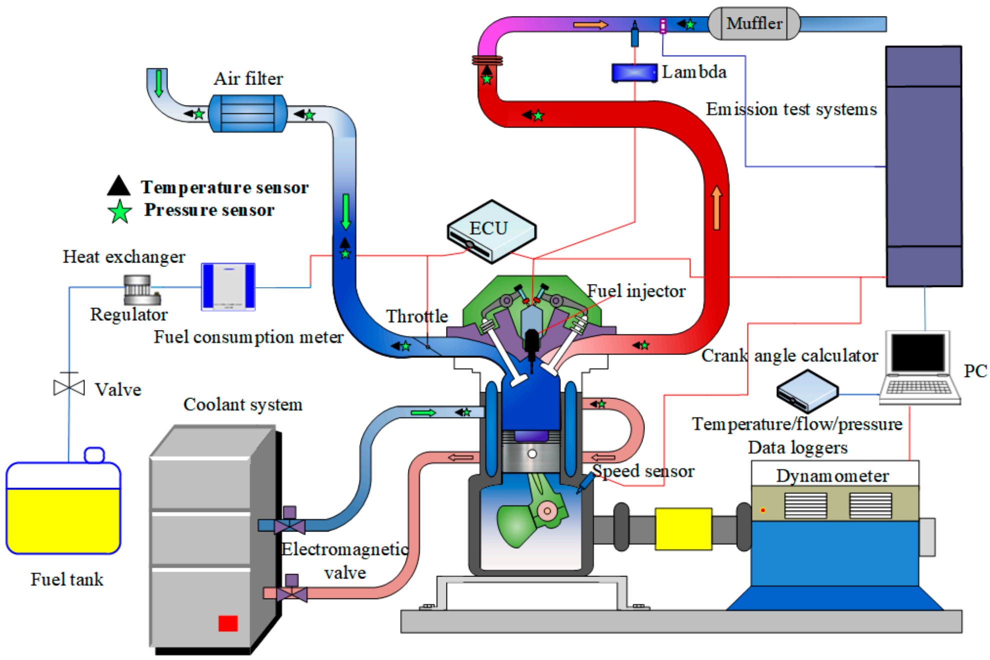

Figure 2. The schematic diagram of the experimental apparatus for diesel engines and instrumentation systems.

Exhaust gas emission analyzers are used to measure major exhaust gases such as unburned hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO). The measurement method of the exhaust gas analyzer and its measurement range, experimental percentage uncertainty, data measurement accuracy and further technical details of the engine and dynamometer are given in Table 3.

To ensure the accuracy and reliability of the results obtained, three independent experiments were conducted. Each experiment was performed under the same conditions to minimize the impact of external factors on the measurements. The measurements were carried out using a range of high-precision instruments that were carefully calibrated before each experiment to minimize measurement errors. Table 3 provides detailed information about the measurement properties, including their specifications and uncertainty levels. The measuring instruments used in the experiments were chosen based on their suitability for the specific parameters being measured, and their accuracy and precision were verified through rigorous calibration procedures. By following strict measurement protocols and carefully selecting the appropriate measuring instruments, we aimed to minimize the potential sources of error and obtain reliable data. Overall, the experimental setup and measurement procedures were designed with utmost care to ensure that the results obtained are accurate and meaningful.

Table 3. The specifications of instruments and equipment.

Instruments	Type	Precision
Dynamometer	Xiangyi Electronic Dynamometer	Torque:±0.2%F.S; Speed: ±5 rpm
Exhaust gas analyzer	AVL DiGas 4000 Light	CO: 0.01% vol HC: 1ppm vol CO_2: 0.02% vol O_2: 0.01% vol NO: 1ppm vol
Smoke meter	FBY-1	±2%F.S
Fuel consumption meter	Xiangyi FC2210	±0.4%
Oil temperature regulator	Xiangyi FC2430T2	±2℃
Water temperature regulator	Xiangyi FC2422	±2℃
Lambda meter	ETAS Lambda Meter	±0.01

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Air flow meter	ToCeil-LFE100	±0.1%
Intake gas temperature sensor	PT100	±0.16℃
Exhaust gas temperature sensor	K type thermocouple	±0.18℃

2.3. Experimental test conditions

In order to guarantee the accuracy of experimental results, all laboratory experiments were conducted under identical operating conditions. Additionally, calibration was performed on all measuring instruments employed to record output data. The level of uncertainty for every device was analyzed and documented in Table 3. Furthermore, atmospheric factors were monitored periodically both before and during experiments to ensure consistent conditions. The test laboratory recorded the temperature, relative humidity, and density of the surrounding air. Sufficient warm-up time was given to the engine to ensure that it attained optimal operating temperatures, such as an engine oil temperature within the range of 77-84℃. The test conditions of the following experiments are shown in the following figures.

3. Results and discussion

3.1. Load characteristics and external characteristics

This experimental study investigated the speed characteristics, load characteristics, exhaust smoke, and gas pollutant emissions of different proportions of tung oil-based biodiesel (B10, B20, B50) and 0# diesel fuel on the ZS1115GM diesel engine. The study also analyzed the influencing factors of these characteristics. Figure 3 and Figure 4 are the economic and power of tung oil-based biodiesel. The maximum power, fuel consumption, maximum torque and smoke of biodiesel with different proportions of biodiesel under different conditions were studied.

Figure 3 shows the maximum power when the throttle is fully open. It can be seen from the diagram that the maximum power and torque of B20 are the smallest, and B10 the largest. Compared with power of 0# diesel, B10 increases by 1.9%, and B20 and B50 decreased by 3.2% and 2.5% respectively. This is because the low calorific value of biodiesel is lower than that of ordinary diesel, then the output power of the diesel engine decreases slightly after adding biodiesel [30].

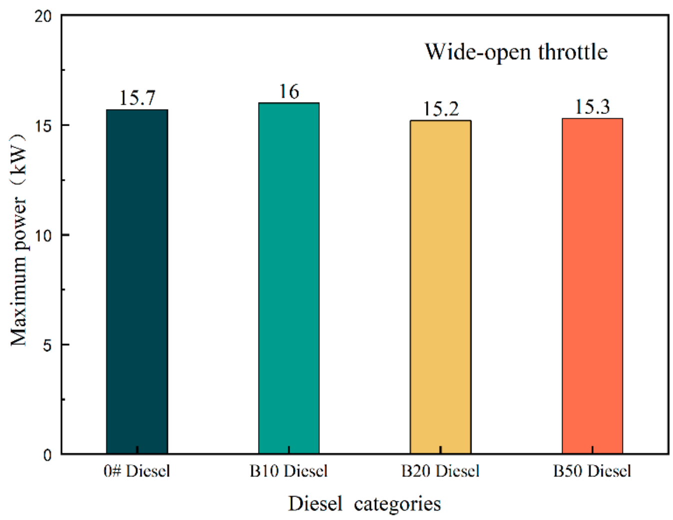

Figure 3. Maximum power.

The maximum torque and the fuel consumption rate at the maximum torque are compared in Figure 4 (B) when the speed is 2200rpm and the power is 14.7kW under the rated condition. As can be seen from the figure, B10 torque is the largest, and B10 increased nearly by 6.6%. Also, B20 and

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B50 were reduced by 2.4% and 1.2 %. As can be seen, with the proportion of biodiesel increasing, the fuel consumption rate became higher.

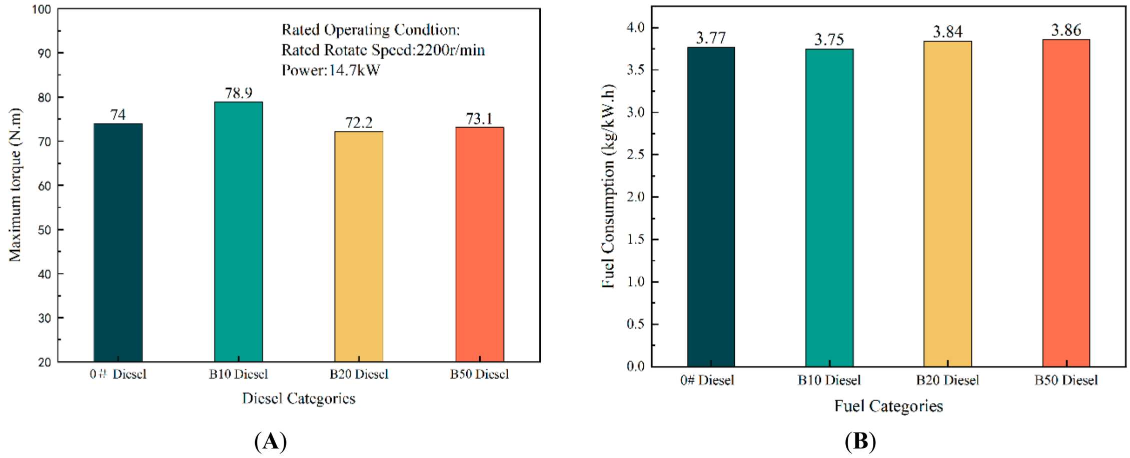

Figure 4. The maximum torque.

The fuel consumption rate at 2200rpm and 14.7kW under rated conditions has been presented in Figure 5. As shown in the figure, the fuel consumption rate increases with the increase in the biodiesel ratio. The fuel consumption rate of B10 is 0.9g/ kW·h lower than that of $0^{\#}$ diesel. The fuel consumption rate of B50 increases the most, and B50 increases by nearly 5.3%. The viscosity of biodiesel is too large, the residual carbon value is high, and the cetane number and calorific value are lower than those of petrochemical diesel [31]. The energy released by the same volume of diesel biodiesel blended fuel is lower than that of petrochemical diesel. At the same time, the thermal polymerization of biodiesel molecules leads to incomplete combustion, and more carbon deposits are formed in the diesel engine, which greatly increases the friction resistance and affects the performance of the diesel engine. The low volatility of biodiesel will affect the quality of the spray and the formation of the mixture, resulting in deterioration of combustion and instability of the diesel engine [32]. Therefore, the fuel consumption rate of biodiesel increases and the economic performance decreases, especially for using B50 biodiesel.

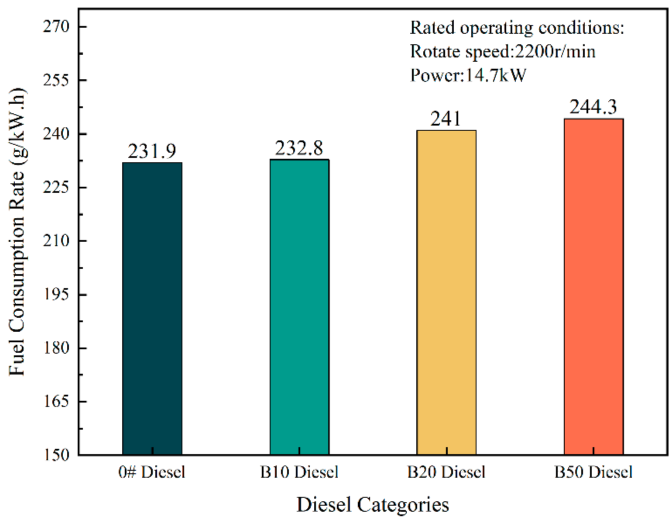

Figure 5. Fuel Consumption Rate.

3.2. Emission characteristic

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The changes in gas exhaust pollutants and soot under different proportions of biodiesel are demonstrated in Figures 6, 7, 8, and 9. The CO emissions at rated speed and different rated loads are represented in Figure 6. It can be seen that B10 has the most obvious effect on reducing CO emissions at different rated loads. Diesel has the most CO emissions at 100% rated load. CO emissions from 100% load to 75% load decrease sharply, while CO emissions from 75% to 10% rated load fluctuate little. When the engine operates at 100% load, the fuel consumption is significantly high. This is evident from Figure 8, where the concentrated mixture's incomplete combustion due to insufficient oxygen leads to a rapid surge in CO emissions. In particular, the CO-specific emissions of B10 decreased by 42.86% at 75% load compared to $0^{\#}$ diesel, while that of B50 increased by 60% at 25% load. The formation of CO is primarily influenced by oxygen concentration and serves as an indicator of complete combustion. At loads exceeding 20%, the high combustion temperature within the cylinder is a result of significant fuel injection. At this time, the oxygen concentration is the main influencing factor of CO formation. The conventional $0^{\#}$ fuel itself does not contain oxygen, while the oxygen-containing characteristics of biodiesel itself improve the anoxic condition and reduce CO emissions. When the load is less than 20%, compared to that of diesel oil the higher viscosity of biodiesel [33,34] has caused difficult fuel atomization and incomplete combustion. An increase in CO formation may be attributed to this factor. [35].

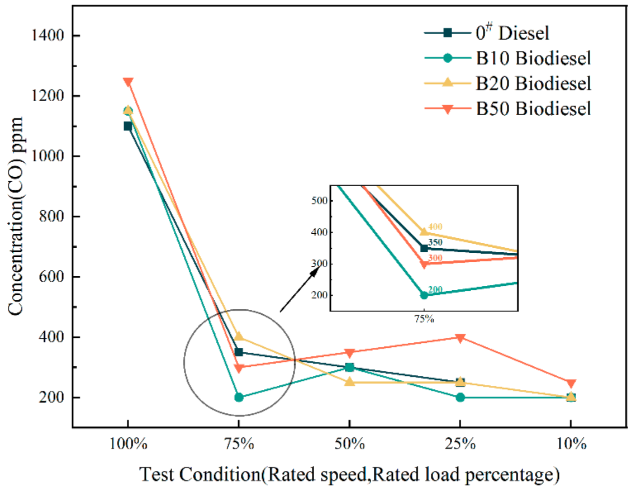

Figure 6. CO Emissions.

Figure 7 demonstrated the NO_x emissions under different rated loads at rated speed and the exhausted temperature at 100% load. Except for B50, if the rated load is constant, increasing the proportion of tung oil in diesel results in lower NOx emissions. Conversely, as the rated load decreases, NOx emissions also decrease. The emission curves when the load is 50% and 75% are shown in the figure, which can clearly see the above situation. But B50 has higher NO_x emissions than B20. The reason for the lower increase in oxygen content when blended in a smaller proportion lies in the inherent characteristics of biodiesel. Its high cetane number and low aromatic content naturally lead to a reduction in combustion temperature. This reduction in temperature leads to a decrease in NO_x emissions. When adding a large proportion, the excess oxygen in the mixed fuel causes the atmosphere of NO_x generation. In addition, due to the low calorific value of biodiesel, the combustion temperature of the higher proportion of mixed fuel may decrease, and the exhaust temperature of B50 increases, as shown in Figure 7 (B). The combined effect of these three factors may lead to an increase in NO_x emissions of the higher proportion of mixed fuel [35,36,37]. Also, the air-fuel ratio under different loads is shown in Figure 8. When the diesel engine load increases, the fuel supply increases and the air-fuel ratio gradually decreases. As the air-fuel ratio decreases, NO_x emissions increase. When the air-fuel ratio gradually increases, the air increases, and the temperature in the cylinder decreases, thereby NO_x emissions decrease.

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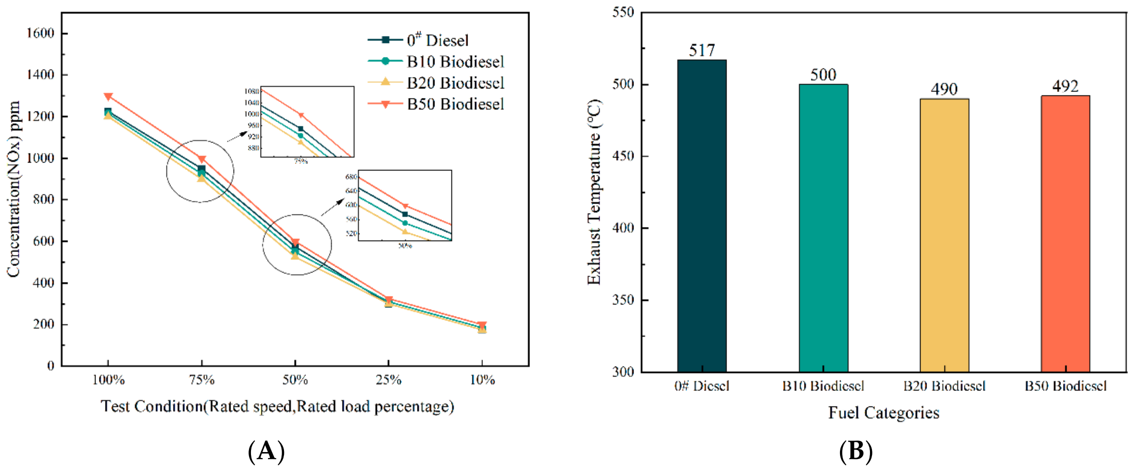

Figure 7. NO_x Emissions and Exhaust Temperature.

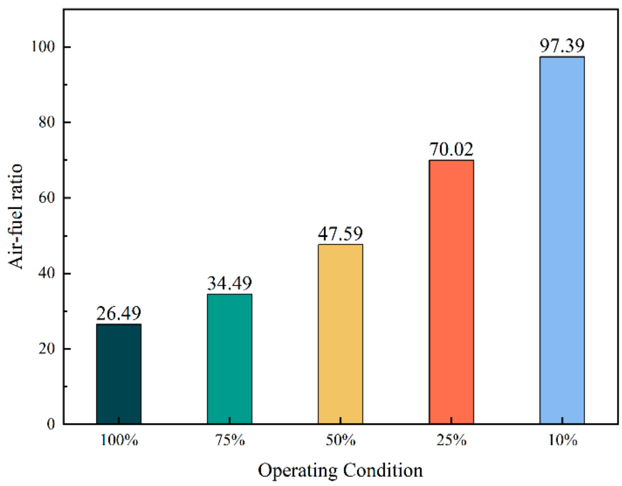

Figure 8. Air-fuel ratio under different loads.

According to Figure 9, it illustrated the HC emission at rated speed and different rated loads. As the load decreases, HC emissions increase first and then decrease. When the load is 50%, HC emissions are the most. When the load is 100%, HC emissions are minimal. The most obvious is that when the load is 50 %, the HC emission of B20 is reduced by 27.54 % compared with 0# diesel. In addition, HC-specific emissions of tung oil-based biodiesel blends were all reduced, especially for B20 decreased by 21.90% at 10% load. But overall, the B20 shows the best performance, with the most significant reduction in HC emissions. This is because when added in small proportions, the added oxygen in biodiesel makes the fuel burn more fully, with more particulates and unburned HC burning before leaving the combustion chamber, so emissions are less.

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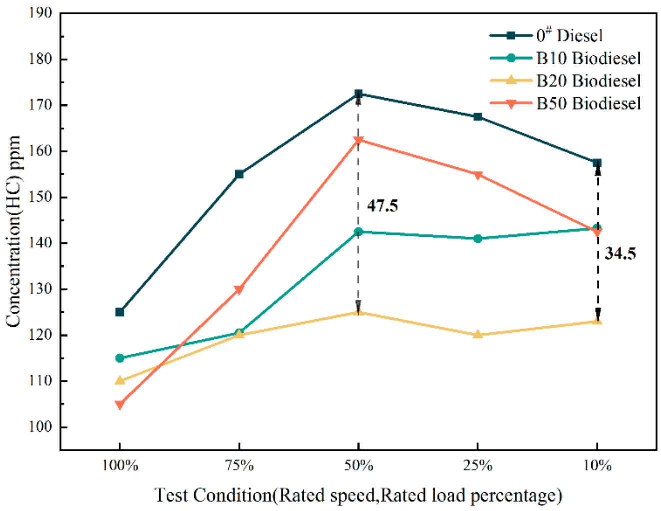
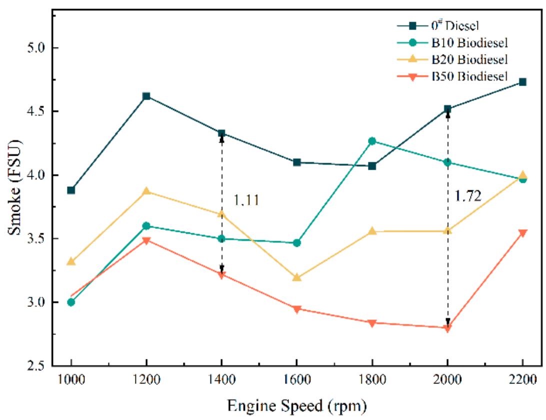


Figure 9. HC Emissions.

Figure 10 (A) exhibits the change in the emission smoke of tung oil-based biodiesel with different speeds of rated power. As can be seen from the figure, usually at 1200 r/min and 2200r/min smoke emission is the highest. B20 and B50 smoke emission for ordinary biodiesel has a significant reduction. In particular, Smoke emissions decreased with increasing percentage of tung oil added, especially for B50 decreased by 38.05% at 2000 rpm. Figure 10 (B) shows the change of smoke of different biodiesel at the same speed. In rated working condition, the smoke degree (FSU) decreases sequentially with the increase in the proportion of tung oil. B50 is reduced the most, reducing by nearly 41% at a speed of 2200 rpm and power of 14.7kW. Figure 10 (C) shows the maximum smoke from different biodiesels.

First of all, biodiesel contains fewer aromatic hydrocarbons. In general, the higher the aromatic hydrocarbons contained in the fuel, the greater its smoke. The emission of soot from biodiesel is lower compared to pure diesel because the smoke produced by the fuel decreases with increasing amounts of alkanes. In addition, biodiesel is an oxygenated fuel (oxygen content of 10%), in the fuel combustion process, oxygen atoms play a role in fuel. Especially in areas with high fuel concentration, after the fuel is oxygenated, the fuel can be burned more completely. It can reduce soot emissions. And smoke reduces as the ambient temperature decreases. [38,39,40].



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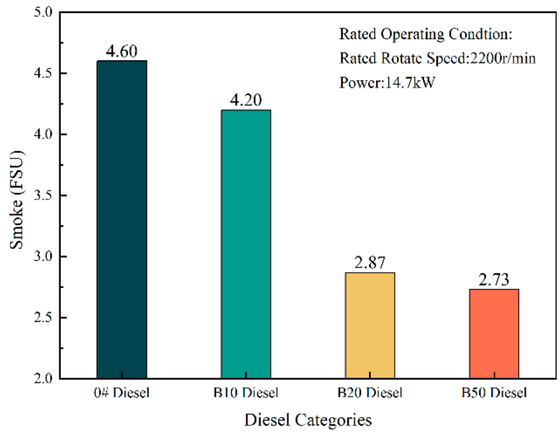

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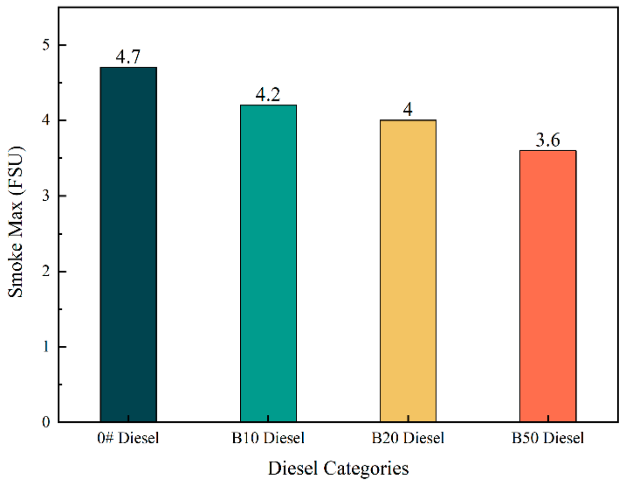

(C)

Figure 10. Smoke.

Detailed comparative data can be seen in the following table. It involved that the emissions, specific emissions, specific emission reductions, and specific emission reduction rates of various exhaust gases under different rated loads.

Table 4. The emissions, specific emissions, specific emission reductions and specific emission reduction rates of various exhaust gases.

Item	B10 Biodiesel			B20 Biodiesel			B50 Biodiesel			$0^{\#}$ Diesel		
Exhaust gas	NO_x (10^{-6})	HC (10^{-6})	CO (10^{-6})	NO_x (10^{-6})	HC (10^{-6})	CO (10^{-6})	NO_x (10^{-6})	HC (10^{-6})	CO (10^{-6})	NO_x (10^{-6})	HC (10^{-6})	CO (10^{-6})
100 % rated load	1215	115	1150	1200	110	1150	1300	105	1250	1225	125	1100
75 % rated load	925	121	200	900	120	400	1000	130	300	950	155	350
50 % rated load	550	143	300	525	125	250	600	163	350	575	173	300
25 % rated load	310	141	200	300	120	250	325	155	400	300	168	250
10 % rated load	185	143	200	175	123	200	200	143	250	175	158	200
Specific emission (g/kW·h)	12.3	0.80	3.50	8.64	0.60	3.70	9.48	0.80	4.30	8.89	0.90	3.70
Specific emission reduction(g/kW·h)	-3.41	0.10	0.20	0.25	0.30	0.00	-0.59	0.10	-0.60	/	/	/
Specific emission reduction rate %	-38.3	11.1	5.41	2.8	33.3	0.0	-6.6	11.1	-16.2	/	/	/

4. Conclusion

Biodiesel was prepared from tung oil by conventional transesterification. The major physical and chemical properties of biodiesels and their combined blends were tested by ASTM standard. The performance and emission characteristics of 10%, 20% and 50% tung oil-based biodiesel blends were studied on a single-cylinder direct injection diesel engine. Based on the above research, the following conclusions can be drawn on it:

1) In terms of economy and power performance, compared with the use of $0^{\#}$ diesel, the maximum power at full load is 16kW for B10, which is 1.9% higher than $0^{\#}$ diesel. In terms of torque, the B10 increased by almost 6.6%. But the B20 and B50 decreased by 2.4% and 1.2%, respectively. The fuel consumption rate of B50 increases the most, and it increases by nearly 5.3%. This is mostly due to the calorific value of biodiesel, cetane number and other parameters that are quite different from diesel.

2) From the analysis of exhaust emission of the blends, it has been found that the NO_x emissions blends decrease as increasing the proportion of tung oil-based except B50. B10 has the most obvious effect on reducing CO emissions at different rated loads. B20 shows the best performance with the most significant reduction in HC emissions. Biodiesel fuel reduces the exhaust emission such as CO, HC, and NO_x, the CO-specific emissions of B10 decreased by 42.86% at 75% load compared to $0^{\#}$

diesel, while that of B50 increased by 60% at 25% load. Compared to 0# diesel, NO_x-specific emissions of tung oil-based biodiesel blends were reduced at all load conditions, except for B50. In addition, HC-specific emissions of tung oil-based biodiesel blends were all reduced, especially for B20 decreased by 22.15% at 10% load.

3) When burning biodiesel, the exhaust smoke of biodiesel is significantly reduced. B50 is reduced the most, reducing by nearly 41%. This is because biodiesel contains fewer aromatic hydrocarbons, and biodiesel is an oxygen-containing fuel during fuel combustion.

The results show that if tung oil-based biodiesel is burned on the engine, the fuel injection system should to be optimized to improve SFC and exhaust emissions. Further research could focus on enhancing the stability of the fuel, reducing NOx emissions and exploring uncontrolled emissions such as smoke and particulate matter.

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Nomenclature

ASTM	American Society of Testing Materials
AV	Acid value
B10	10% Tung oil, 90% 0# diesel
B20	20% Tung oil, 80% 0# diesel
B50	50% Tung oil, 50% 0# diesel
CFPP	Cold filter plugging point
CN	Cetane number
EGR	Exhaust Gas Recirculation
KV	Kinematic viscosity
NO_x	Oxides of nitrogen
SFC	Specific Fuel Consumption
Φ	Equivalence ratio

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