Study on Combustion Dynamic Performance of Woody Plant Based Hydrocarbon Fuel

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Abstract. Woody plant oil is a kind of biological material which occupies an important position. It has many characteristics, such as wide variety, wide distribution, large yield and reproducible. The thermochemical conversion technology of woody vegetable oils is an efficient conversion route, and the obtained hydrocarbon-rich fuel can maximize the proximity to existing fossil fuels by esterification and acid reduction. At present, the research on the combustion performance of hydrocarbon rich fuels is relatively few. In this study, B20 (hydrocarbon enriched fuel 20%, #0 diesel 70%) and #0 diesel were used for reference. The results show that, under the same conditions, the emission performance of B20 (smoke, CH, CO, NOx) of the woody plant based hydrocarbon fueled fuel is better than that of #0 diesel. The dynamic performance (torque performance, power performance) is basically equal to that of #0 diesel, and it can protect the ecological environment well, and has a good application prospect.

1. Introduction
Fossil energy and chemical products have penetrated into various industries, and with the rapid development of economy, the use of energy and chemical products has shown a rapid increasing trend, resulting in the gradual deterioration of human ecological environment, so how to develop and utilize new environmentally friendly liquid fuels to reduce carbon dioxide emissions in the atmosphere is an important research direction [1,2]. Among all kinds of renewable resources, woody vegetable oil is an important biological raw material, which has the advantages of wide distribution of planting area, many kinds of cultivation, large annual yield of oil, recycling and so on, and is an important raw material for the preparation of bio-based renewable energy chemicals [3,4]. At present, the development of biodiesel from woody oil has established many large-scale production enterprises [5,6]. Although biodiesel has better ecological and environmental benefits than fossil fuels, and biodiesel aromatics have lower chemical content, lower sulfur content and excellent safety performance, biodiesel also has certain defects, such as the kinematic viscosity is high, the calorific value is low, and the physical and chemical properties of biodiesel products vary greatly with different raw materials. These disadvantages limit the application depth and application range of biodiesel to a certain extent[7,8].
The thermochemical conversion technology of woody vegetable oils is an efficient conversion route, and its products can maximize the access to existing fossil fuels. Although the catalytic cracking process has many advantages, the obtained hydrocarbon-rich fuel contains more free fatty acids and aldehyde-based compounds, and the fuel acid value is generally higher than 40 mgKOH·g⁻¹ [9]. Therefore, the hydrocarbon-rich fuel is usually subjected to acid reduction and then the formula can be used as an engine fuel. Chen Jie et al [10] studied the preparation of tung-oil-based petrochemical diesel fuel by catalytic cracking and catalytic esterification. It was found that the acid value of the fuel could be effectively reduced after esterification, the calorific value of combustion was increased, and the quality of hydrocarbon-rich fuel was improved.

At present, there are few studies on the combustion dynamics of hydrocarbon-rich fuels, mainly focusing on the bench test of biodiesel [11]. Lei Kelin et al [12] systematically studied the combustion dynamic performance and fuel stability performance of biodiesel with different ratios of ethanol and diesel. It was found that the tail gas emission performance of fuel had advantages and the dynamic performance decreased slightly. In the current research, biodiesel prepared from waste oil (hydrophobic oil, acidified oil), rapeseed oil, jatropha oil and other kinds of oils was subjected to bench test on the engine [13, 14]. This study used B20 (hydrocarbon-rich fuel 20%, 0# diesel 70%) and 0# diesel for reference comparison, which provided theoretical guidance and laid the foundation for the use of hydrocarbon-rich fuel on existing locomotives.

2. Materials and methods

2.1. Experimental materials and reagents
D2 Exhaust Gas Analyzer (Beckman); CMFD010 engine instantaneous fuel consumption measuring instrument (Shanghai Tongyuan Engine Testing Equipment Co., Ltd.); FC2000 Engine Measurement and Control System (Xiangyi Power Test Instrument Co., Ltd.); GW100 eddy current dynamometer (Xiangyi Power Test Instrument Co., Ltd.); FC2210Z intelligent fuel consumption meter (Xiangyi Power Testing Instrument Co., Ltd.); FQD-102A Digital Exhaust Smoke Meter (Beijing Hao Naite Technology Co., Ltd.). Woody plant based hydrocarbon-rich fuel (made by Hunan Academy of Forestry); 0# Diesel (Changsha China Petroleum Gas Station purchase).

2.2. Experimental Methods

2.2.1. Dynamic test method. GB/T 1147.1-2007 "Medium and small power internal combustion engines Part 1: General technical conditions"; GB/T 1147.2-2007 "Medium and small power internal combustion engines - Part 2: Experimental methods”.

2.2.2. Temperament analysis method. Chromatographic conditions [15]: FID detector, OV-1 column (30.0m×0.25mm×0.25μm); Helium is a carrier gas, the flow rate is 10.0 mL·min⁻¹, the injection volume is 1.0 μL, the inlet temperature is 280.0°C, and the ion chamber temperature is 250.0°C. Program temperature conditions: programmed temperature, initial temperature 100.0°C (keep 5.0 min), temperature rise rate of 15.0°C·min⁻¹ rose to 280.0°C (maintained 10.0 min). Mass spectrometry conditions: Scion SQ single quadrupole mass spectrometer, electron bombardment (EI) ion source, electron energy 70.0 eV; The quadrupole temperature is 150.0°C; the ion source temperature is 230.0°C; the mass scan range is 33-350 amu.

2.2.3. Fourier infrared FT-IR characterization. Fourier infrared spectroscopy characterization conditions [16]: The detector is a mid-infrared DTGS detector with a wavenumber scanning range of 400.0 cm⁻¹-4000.0 cm⁻¹ and a resolution of 4.0 cm⁻¹.
3. Results and analysis

3.1. Hydrocarbon-rich fuel gas mass spectrum
The wood-based plant-based hydrocarbon-rich fuel is obtained by pyrolysis of plant oils, and the composition is relatively complicated. The results of gas chromatography and mass spectrometry analysis are shown in Figure 1.

![Fig. 1 GC-MS of hydrocarbon enriched fuel.](image)

It can be seen from Fig.1 that the main components of the woody plant-based hydrocarbon-rich fuel include 26.29% methyl octadecanoate, 22.01% Methyl palmitate, 8.51% methyl decanoate, 5.14% methyl heptanoate, 2.62% Methyl octanoate, 2.31% Pentadecane, 2.01% Methyl decanoate, 1.82% octane. Because the hydrocarbon-rich fuel passes through the high temperature, a small amount of polymerized hydrocarbons are formed, mainly 0.95% of the 23 hydrocarbon.

3.2. Infrared spectrum of hydrocarbon-rich fuel
The molecular functional groups of the woody plant-based hydrocarbon-rich fuel and their distribution can be analyzed by Fourier transform infrared spectroscopy. The results are shown in Fig. 2.

![Fig. 2 FT-IR spectra of hydrocarbon enriched fuel.](image)

It can be seen from Fig. 2 that the main absorption peaks of woody plant-based hydrocarbon-rich fuels are as follows: the range of 3000cm⁻¹-2800cm⁻¹ is saturated C-H stretching vibration absorption, 1460cm⁻¹-1340cm⁻¹ is saturated C-H bending vibration; olefin C-H stretching vibration absorption between 3100cm⁻¹-3000cm⁻¹, 1670cm⁻¹-1650cm⁻¹ is C=C stretching vibration absorption; 1750 cm⁻¹-1735cm⁻¹ interval is ester C=O absorption band, and 1210cm⁻¹-1163cm⁻¹ is ester C-O absorption band.
3.3. Load characteristic detection

The load characteristic is a study of the relationship between fuel consumption and engine load, and is an important indicator for assessing the economic performance of fuel.

| Serial number | Rotating speed (r min⁻¹) | Torque (N.m) | Power (kw) | Fuel consumption (kg h⁻¹) | Fuel consumption rate(g kw⁻¹ h⁻¹) | Oil temperature (°C) | Exhaust gas temperature (°C) |
|---------------|--------------------------|--------------|-----------|----------------------------|-----------------------------------|----------------------|-------------------------------|
| 1             | 2201                     | 15.5         | 3.6       | 1.220                      | 340.4                             | 100.6                | 230                           |
| 2             | 2201                     | 32           | 7.4       | 1.860                      | 252.1                             | 100.1                | 303                           |
| 3             | 2201                     | 47.9         | 11        | 2.540                      | 229.9                             | 101                  | 391                           |
| 4             | 2198                     | 57.5         | 13.3      | 3.030                      | 228.2                             | 102.2                | 452                           |
| 5             | 2202                     | 63.6         | 14.7      | 3.410                      | 231.9                             | 101.9                | 491                           |
| 6             | 2198                     | 68.2         | 15.7      | 3.69                       | 234.3                             | 103.9                | 529                           |

It can be seen from Table 1 and Table 2 that the load characteristics of B20 and 0° diesel are basically the same at the same speed, but the fuel consumption of B20 is slightly higher than that of 0° diesel under certain speed conditions, which is mainly due to the presence of B20 fuel. Certain oxygen elements cause a slight decrease in the energy density of the fuel.

3.4. Rated nitrogen oxides

The speed characteristic refers to the relationship between the engine throttle opening or the throttle opening and the engine performance index as a function of the rotational speed, and the purpose is to study the dynamic performance of the engine.

| Serial number | Rotating speed (r min⁻¹) | Torque (N.m) | Power (kw) | Fuel consumption (kg h⁻¹) | Fuel consumption rate(g kw⁻¹ h⁻¹) | Oil temperature (°C) | Exhaust gas temperature (°C) |
|---------------|--------------------------|--------------|-----------|----------------------------|-----------------------------------|----------------------|-------------------------------|
| 1             | 2199                     | 64           | 14.7      | 3.42                       | 232.1                             | 104.6                | 494.4                         |
| 2             | 1999                     | 71.8         | 15        | 3.39                       | 225.4                             | 104.3                | 495.4                         |
| 3             | 1800                     | 74           | 13.9      | 3.13                       | 224.5                             | 104                 | 490.2                         |
| 4             | 1599                     | 77.1         | 12.9      | 2.841                      | 220.2                             | 101.8                | 474                           |
| 5             | 1399                     | 77.1         | 11.3      | 2.499                      | 221.1                             | 99.5                 | 445.4                         |
| 6             | 1200                     | 76.3         | 9.6       | 2.147                      | 223.9                             | 96.7                 | 427.5                         |

| Serial number | Rotating speed (r min⁻¹) | Torque (N.m) | Power (kw) | Fuel consumption (kg h⁻¹) | Fuel consumption rate(g kw⁻¹ h⁻¹) | Oil temperature (°C) | Exhaust gas temperature (°C) |
|---------------|--------------------------|--------------|-----------|----------------------------|-----------------------------------|----------------------|-------------------------------|
| 1             | 2199                     | 63.9         | 14.7      | 3.43                       | 233.2                             | 93.8                 | 486.4                         |
| 2             | 2000                     | 72.6         | 15.2      | 3.47                       | 228.1                             | 98.4                 | 507.1                         |
| 3             | 1800                     | 73.7         | 13.9      | 3.137                      | 225.7                             | 99.6                 | 490                           |
| 4             | 1600                     | 77.8         | 13        | 2.89                       | 221.6                             | 98.9                 | 477.4                         |
3.5. Speed characteristic smoke test result

Smoke detection is the degree of blackening of the filter paper through which the specified volume of exhaust gas passes, the rated power of this experimental condition is set to: 2200 r/min and 4.7 kw.

Table 5 The smoke detection results of motor speed characteristic

| Serial number | Rotating speed (r·min⁻¹) | Exhaust smoke detection result (FSU) | B20 exhaust smoke change |
|---------------|--------------------------|-------------------------------------|--------------------------|
|               |                          | 0°Diesel oil                        | B20                      |
|               |                          |                                    | Reduced value (FSU)      |
|               |                          |                                    | Reduction rate(%)        |
| 1             | 2200                     | 4.13                                | 3.97                     | 0.17 | 4.0 |
| 2             | 2000                     | 4.27                                | 4.10                     | 0.17 | 3.9 |
| 3             | 1800                     | 4.47                                | 4.27                     | 0.20 | 4.5 |
| 4             | 1600                     | 3.60                                | 3.47                     | 0.13 | 3.7 |
| 5             | 1400                     | 3.70                                | 3.50                     | 0.20 | 5.4 |
| 6             | 1200                     | 3.87                                | 3.60                     | 0.27 | 6.9 |
| 7             | 1000                     | 3.27                                | 3.00                     | 0.27 | 8.2 |

It can be seen from Table 5 that the B20 speed characteristic smoke detection result is better than 0° diesel oil because the B20 blending fuel contains a certain amount of oxygen element, which is beneficial to the full combustion of the fuel.

3.6. Exhaust emission test

Engine exhaust gas inspection indicators mainly include CO, HC and NOx, and the test results are shown in Table 6.

Table 6 The detection results of exhaust emission test

| Test conditions| Discard ingredients(10⁻⁶) | NOx | CO | NOx | HC  | CO  |
|----------------|---------------------------|-----|----|-----|-----|-----|
| Rated speed, 100% rated load | 1427 | 137 | 1150 | 1506 | 99  | 1400 |
| Rated speed, 75% rated load   | 1200 | 112 | 200  | 1228 | 139 | 300  |
| Rated speed, 50% rated load   | 713  | 143 | 300  | 775  | 157 | 330  |
| Rated speed, 25% rated load   | 375  | 114 | 200  | 383  | 148 | 200  |
| Rated speed, 10% rated load   | 213  | 143 | 200  | 222  | 143 | 200  |
| Specific emissions (g·kw⁻¹·h⁻¹) | 12.3 | 0.80 | 3.5  | 12.80 | 0.90 | 4.10 |
| Specific emission reduction (g/kw/h) | 0.50 | 0.10 | 0.60 | /     | /   | /    |

It can be seen from Table 6 that the specific emissions of B20 fuel and 0° diesel are 13.1 (NOx 12.3 and HC 0.80) and 13.7 (NOx 12.3 and HC 0.80), respectively, and the B20 exhaust emission test results are better than 0° diesel. The CO, HC and NOx in the engine exhaust mainly result from insufficient combustion of the fuel in the internal combustion engine. During engine operation, the oxygen content in the combustion chamber and the emissions are closely related to the emissions of the exhaust. Under the precursor of ensuring that the work is basically the same as that of 0° diesel, the oxygen element in B20 has a combustion-supporting effect, which can improve combustion and has a good environmental protection prospect.
4. Conclusion and discussion
The conclusions of the investigation on the combustion dynamic performance of wood-based plant-based hydrocarbon-rich fuels are as follows:

- The wood-based plant-based hydrocarbon-rich fuel composition is relatively complex, mainly including 26.29% methyl octadecanoate, 22.01% methyl palmitate, 8.51% methyl decanoate, 5.14% methyl heptanoate, 2.62% methyl octanoate, 2.31% fifteen alkane, 2.01% methyl decanoate, 1.82% octane.
- The emission performance (smoke, CH, CO, NOx) of wood-based plant-based hydrocarbon-rich fuel B20 is better than # diesel. The dynamic performance indexes such as torque performance and power performance of the bench test are slightly lower than those of # diesel, but it can protect the ecological environment well and has a good application prospect.

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