Study of Viscosity-Temperature Characteristics of Rice Bran Oil-Based Biodiesel Fuel

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Abstract

The effect of temperature on kinematic viscosity of rice bran oil biodiesel, i.e. rice bran oil methyl ester (RBME) is investigated. Viscosity-temperature equations are proposed for predicting kinematic viscosity of RBME, RBME/0 petrodiesel (0PD) and RBME/-10 petrodiesel (-10PD) at different temperature. The objective is to show that RBME is mainly composed of fatty acid methyl esters of 14-26 even-numbered C atoms: $C_{14:0}$-$C_{26:0}$, $C_{16:1}$-$C_{20:1}$, $C_{18:2}$ and $C_{18:3}$. The kinematic viscosity (40 ℃) of RBME is 7.16 mm^2/s. RBME has higher kinematic viscosity and unfavorable viscosity temperature characteristic. An approach to reduce viscosity and enhance viscosity - temperature characteristic is put forward: blending with 0PD or -10PD.

Keywords

Biodiesel, Rice bran oil, Kinematic viscosity, Viscosity - temperature characteristic.

1. Introduction

The major reason to be considered as driving force to look for alternative energy resources, like biodiesel, is fossil fuels exhaustion and environmental pollution. Biodiesel is defined as the fatty acid alkyl esters of vegetable oils and animal fats [1]. The cost of biodiesel is likely to be a barrier for its development due to the fact that most of the biodiesel produced is from edible oil. One way of reducing the biodiesel costs is to use non-edible oils such as rice bran oil [2]. China is the largest rice producer of the world. 2015, rice yield is 208,245,000 ton/year [3]. Rice bran oil is a byproduct of rice. Depending on variety of rice and degree of milling, rice bran contains 15%–23% lipids [4]. Hence, rice bran oil is a suitable raw material for biodiesel production. However, the viscosity of rice bran oil biodiesel, i.e. rice bran oil methyl ester (RBME) is higher, which reaches the kinematic viscosity upper limits (1.9-6.0 mm^2/s, at 40 ℃) of GB/T 20828-2007 standards for biodiesel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors [5-6]. In this paper, attempt has been made to investigate the impact of petrodiesel and temperature on RBME kinematic viscosity. It can be expected to provide some help for the selection of petrodiesel and its blending ratio that are beneficial for reducing a RBME kinematic viscosity, thus improving the atomization characteristic of a higher viscosity RBME by adding some suitable petrodiesel into it.

2. Experimental

2.1 Materials.

0 petrodiesel (0PD) and -10 petrodiesel (-10PD) are purchased from China Petroleum & Chemical Corporation; RBME is prepared by our laboratory, in line with GB/T 20828-2007 requirements.

2.2 Composition Analyzed.

Oil samples are analyzed by gas chromatography-mass spectrometer (GC-MS) (Finnigan, Trace MS, FID, USA), equipped with a capillary column (DB-WAX, 30 m × 0.25 mm × 0.25 μm). The carrier gas is helium (0.8 ml/min). The sample injection volume is 1 μl. Temperature program is started at

160 ℃, staying at this temperature for 0.5 min, heated to 215 ℃ at 6 ℃ /min, then heated to 230 ℃ at 3 ℃ /min, staying at this temperature for 13 min.

2.3 Kinematic Viscosity Measured.

The kinematic viscosity of oil samples is measured in accordance to GB/T 265-1988, using the SYP1003-6 Kinematic Viscosity Tester and SYP1003-7 Kinematic Viscosity Low Temperature Tester (Shanghai BOLEA Instrument & Equipment Co., Ltd., China).

2.4 Composition.

The main chemical composition of 0PD, -10PD and RBME analyzed by GC-MS is shown in Table 1 and Table 2.

Table 1. The main chemical composition of 0PD and -10PD (w)/%

Content	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{24}	C_{26}
0PD	0.00	0.00	5.85	9.91	7.88	1.80	6.42	6.91	9.15	3.76	6.53	6.41	3.97	3.92	2.59	0.00	0.00
-10PD	0.36	1.75	5.51	4.09	6.70	2.24	4.37	12.69	3.83	6.65	1.38	0.81	1.35	8.52	0.00	0.74	0.27

Note: C_m is the shorthand of alkane; *m* means the carbon number of alkane.

Table 2. The main chemical composition of 0PD and -10PD (w)/%

RBME	$C_{14:0}$	$C_{16:0}$	$C_{18:0}$	$C_{20:0}$	$C_{22:0}$	$C_{24:0}$	$C_{26:0}$	$C_{16:1}$	$C_{18:1}$	$C_{20:1}$	$C_{18:2}$	$C_{18:3}$
Content	0.36	16.37	2.20	0.73	0.29	0.49	0.29	0.30	42.74	0.64	34.19	1.39

Note: Cm:n is the shorthand of fatty acid methyl ester; *m* means the carbon number of fatty acid; *n* means the number of C=C.

From Table 1, the main chemical compositions of 0PD are the alkane composed by C_{10}-C_{22}, and -10PD by C_8-C_{26}. From Table 2, we can see that dominate the main chemical compositions of RBME are the fatty acid methyl ester (FAME) composed by 14-26 even number carbon atoms, and the mass fraction of saturated fatty acid methyl esters (SFAME) ($C_{14:0}$-$C_{26:0}$) and unsaturated fatty acid methyl esters (UFAME) ($C_{16:1}$-$C_{20:1}$, $C_{18:2}$ and $C_{18:3}$) is 20.73% and 79.26% respectively.

2.5 Viscosity-Temperature Characteristics of 0PD, -10PD and RBME.

The kinematic viscosity (40 ℃) of 0PD, -10PD and RBME is 2.91, 2.53 and 7.16 mm^2/s respectively, and the viscosity-temperature relationships of 0PD, -10PD and RBME are given in Fig. 1. From Fig. 1, we can see that comparing with petrodiesel fuel, kinematic viscosity of RBME is higher, and as the temperature is decreased, RBME viscosity increases rapidly. Thus, viscosity-temperature characteristic of RBME is poor. This is because that FAME has greater kinematic viscosity than their hydrocarbon counterparts for the same number of carbon atoms at same temperature. The viscosity-temperature equation is established: $v_t = 29.346 - 1.203t + 0.018t^2$ R^2=0.984.

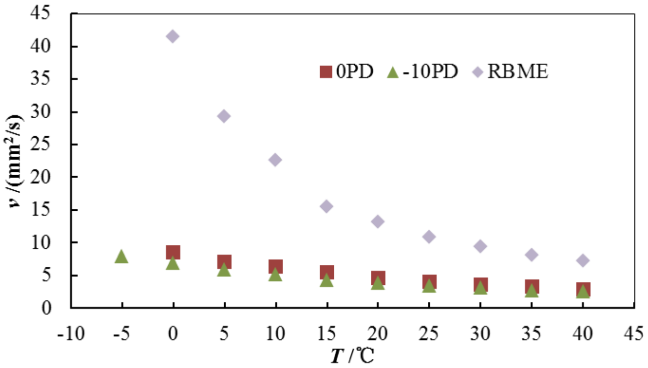


Fig. 1 The viscosity-temperature relationship of 0PD, -10PD and RBME

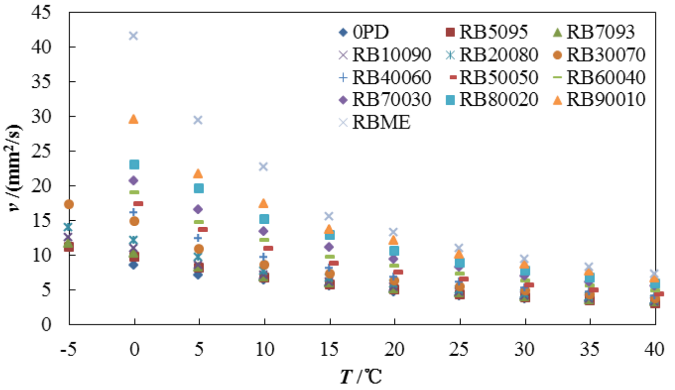
Atomization is the first stage of combustion in the diesel engine. Oxygen in the air will react rapidly with fuel on the outer surface of the oil droplet and releases a tremendous amount of heat to the surrounding. This will initiate other competitive chemical reactions, such as charring or coking and polymerization. Thus, higher viscous fuel, which tend to form larger droplet size, may enhance the polymerization reaction, especially oil of high degree of unsaturation, and ultimately the formation of engine deposits.

Based on lower viscosity and good viscosity-temperature characteristics of 0PD and -10PD (Fig. 1), an approach for reduce viscosity and enhance viscosity-temperature characteristics of RBME is blending with 0PD or -10PD.

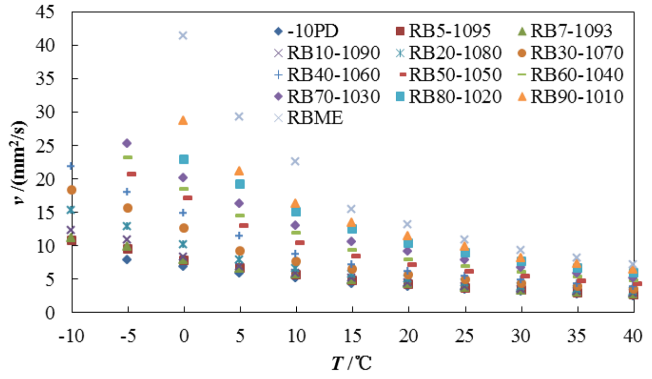
2.6 Viscosity-Temperature characteristics of RBME/0PD and RBME/-10PD.

The kinematic viscosity (40 ℃) and viscosity-temperature relationships of RBME–0PD/-10PD blends are given in Fig. 2. From Fig. 2, we can see that as the 0PD or -10PD ratio increases, RBME/0PD or RBME/-10PD kinematic viscosity decreases from RBME down to 0PD or -10PD. And blend also enhances viscosity-temperature characteristics, viz., as the 0PD or -10PD ratio increases, blend oils kinematic viscosity increases slowly as temperature decreases. Viscosity-temperature equations are established: $v_t = A + BT + CT^2$, in which A, B, C, and determination coefficient R^2 are given in Table 3.

The viscosity-temperature equations have shown good performance to predict the kinematic viscosity of the RBME and its blends.



(a) 0PD



(b) -10PD

Fig. 2 The viscosity-temperature relationship of RBME/0PD and RBME/-10PD

Table 3 The main chemical composition of 0PD and -10PD (w)/%

Blend oil	Temperature Range / ℃	A	B	C	R^2	Blend oil	Temperature Range / ℃	A	B	C	R^2
RB$_{5}$0$_{95}$	-10～40	7.916	-0.253	0.003	0.998	RB$_{5}$-10$_{95}$	-5～40	9.576	-0.299	0.004	0.999
RB$_{7}$0$_{93}$	-10～40	8.165	-0.267	0.003	0.995	RB$_{7}$-10$_{93}$	-5～40	9.920	-0.326	0.004	0.996
RB$_{10}$0$_{90}$	-10～40	8.770	-0.307	0.004	0.991	RB$_{10}$-10$_{90}$	-5～40	10.564	-0.364	0.005	0.993
RB$_{20}$0$_{80}$	-10～40	10.469	-0.407	0.006	0.991	RB$_{20}$-10$_{80}$	-5～40	11.709	-0.414	0.005	0.995
RB$_{30}$0$_{70}$	-10～40	12.446	-0.504	0.007	0.991	RB$_{30}$-10$_{70}$	-5～40	14.165	-0.562	0.008	0.988

RB$_{40}$0$_{60}$	-10～40	14.688	-0.614	0.009	0.995	RB$_{40}$-10$_{60}$	0～40	15.472	-0.601	0.008	0.988
RB$_{50}$0$_{50}$	-5～40	16.865	-0.687	0.010	0.994	RB$_{50}$-10$_{50}$	0～40	17.062	-0.647	0.009	0.993
RB$_{60}$0$_{40}$	-5～40	18.561	-0.745	0.010	0.995	RB$_{60}$-10$_{40}$	0～40	18.421	-0.688	0.009	0.993
RB$_{70}$0$_{30}$	0～40	20.402	-0.790	0.011	0.995	RB$_{70}$-10$_{30}$	0～40	20.082	-0.720	0.009	0.996
RB$_{80}$0$_{20}$	0～40	22.758	-0.823	0.010	0.997	RB$_{80}$-10$_{20}$	0～40	22.956	-0.815	0.010	0.997
RB$_{90}$0$_{10}$	0～40	27.352	-1.124	0.016	0.984	RB$_{90}$-10$_{10}$	0～40	28.111	-1.149	0.016	0.985

3. Conclusion

The above discussion shows that:

RBME is mainly composed of FAME of 14-26 even-numbered carbon atoms, and the mass fraction of SFAME ($C_{14:0}$-$C_{26:0}$) and UFAME ($C_{16:1}$-$C_{20:1}$, $C_{18:2}$ and $C_{18:3}$) is 20.73% and 79.26% respectively. The kinematic viscosity (40 ℃) of RBME is 7.16 mm^2/s. RBME has higher kinematic viscosity and unfavorable viscosity-temperature characteristics. An approach to reduce viscosity and enhance viscosity-temperature characteristics is adopted: blending with 0PD or -10PD. Good performance models are put forward for predicting the kinematic viscosity of RBME, RBME/0PD and RBME/-10PD at different temperature.

Acknowledgements

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