Study of viscosity - temperature characteristics of rapeseed oil biodiesel and its blends

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Abstract

This paper studies the effect of temperature on kinematic viscosity of rapeseed oil biodiesel, i.e. rapeseed oil methyl ester (RME). Viscosity-temperature equations are proposed for predicting kinematic viscosity of RME, RME/0 petrodiesel (0PD) and RME/-10 petrodiesel (-10PD) at different temperature. The objective is to show that RME is mainly composed of fatty acid methyl esters of 16-24 even-numbered C atoms: C16:0-C24:0, $C_{16:1}$-$C_{22:1}$, $C_{18:2}$-$C_{20:2}$ and $C_{18:3}$. The kinematic viscosity (40°C) of RME is 5.62mm^2/s. RME has higher kinematic viscosity and unfavorable viscosity temperature characteristic. An approach to reduce viscosity and enhance viscosity - temperature characteristic of RME is put forward: blending with 0PD or -10PD.

Keywords

Biodiesel, Rapeseed oil, Kinematic viscosity, Viscosity - temperature characteristic.

1. Introduction

As a result of its high thermal efficiency, a Compression Ignition (CI) engine is a popular choice for industrial and domestic power generation applications. As demand for power increases and fossil fuels become more limited, it is important to search a renewable fuel, for instance biodiesel. However, biodiesel may exhibit cold flow properties problem. [1] Cold flow properties of diesel fuel are generally characterized by the following parameters viz. cold filter plugging point (CFPP) and kinematic viscosity (KV), etc. [2-4] However, the viscosity of rapeseed oil biodiesel, i.e. rapeseed oil methyl ester (RME) is higher, which reaches the kinematic viscosity upper limits (1.9-6.0 mm2/s, at 40°C) of GB/T 20828-2007 standards for biodiesel. High viscosity leads to unfavorable cold flow properties, 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 RME 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 RME kinematic viscosity, thus improving the atomization characteristic of a higher viscosity RME by adding some suitable petrodiesel into it.

2. Experimental

2.1 Materials

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

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 °C, staying at this temperature for 0.5 min, heated to 215 °C at 6 °C/min, then heated to 230 °C at 3 °C /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).

3. Results and discussion

3.1 Composition

GC-MS is utilized to analyze the chemical composition of RME, 0PD and -10PD. The gas chromatogram is shown in Fig.1. The chemical composition is shown in Table 1 - Table 2.

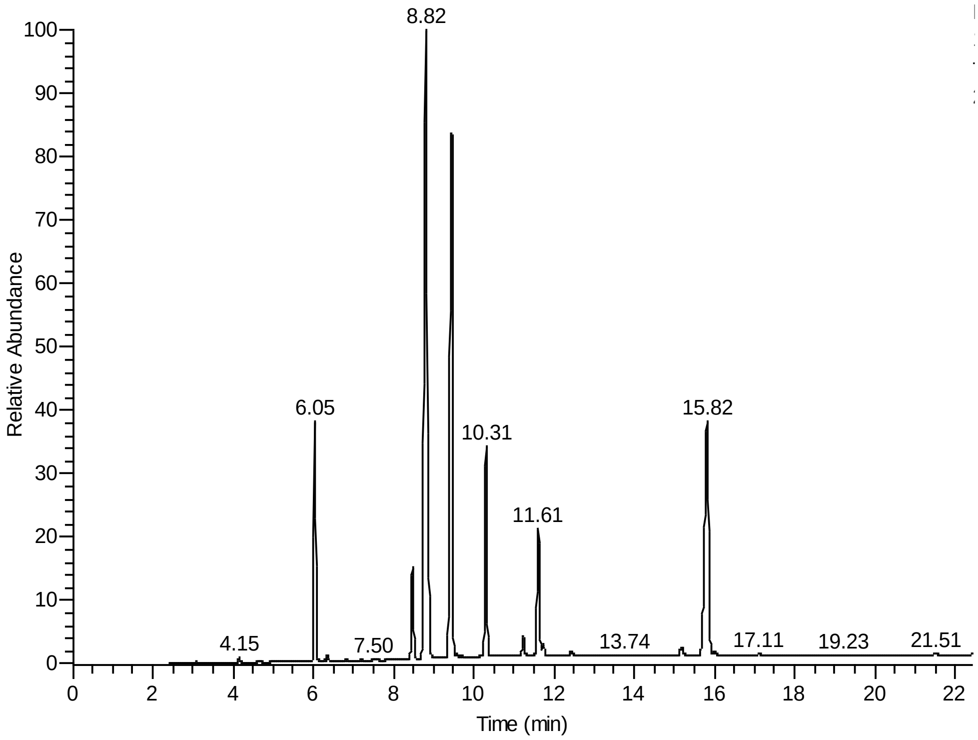


Fig.1 The gas chromatogram of RME2

Table 1 The main chemical compositions of RME (w)/%

RME2	$C_{16:0}$	$C_{18:0}$	$C_{20:0}$	$C_{22:0}$	$C_{24:0}$	$C_{16:1}$	$C_{18:1}$	$C_{20:1}$	$C_{22:1}$	$C_{18:2}$	$C_{20:2}$	$C_{18:3}$
Content	7.57	3.31	0.79	0.50	0.25	0.19	32.96	5.69	15.79	25.06	0.33	7.44

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.

Table 2 The main chemical compositions 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.

From Table 1, we can see that dominate the main chemical compositions of RME are the fatty acid methyl ester (FAME) composed by 16-24 even number carbon atoms, and the mass fraction of saturated fatty acid methyl esters (SFAME) ($C_{16:0}$-$C_{24:0}$) and unsaturated fatty acid methyl esters (UFAME) ($C_{16:1}$-$C_{22:1}$, $C_{18:2}$-$C_{20:2}$ and $C_{18:3}$) is 12.42% and 87.46% respectively. From Table 2, the main chemical compositions of 0PD are the alkane composed by C_{10}-C_{22}, and -10PD by C_8-C_{21}, C_{24} and C_{26}.

3.2 Viscosity-Temperature Characteristics of RME, 0PD and -10PD

The kinematic viscosity (40 °C) of RME, 0PD and -10PD is 5.62, 2.91 and 2.53 mm^2/s respectively, and the viscosity-temperature relationships of RME, 0PD and -10PD are given in Fig. 2.

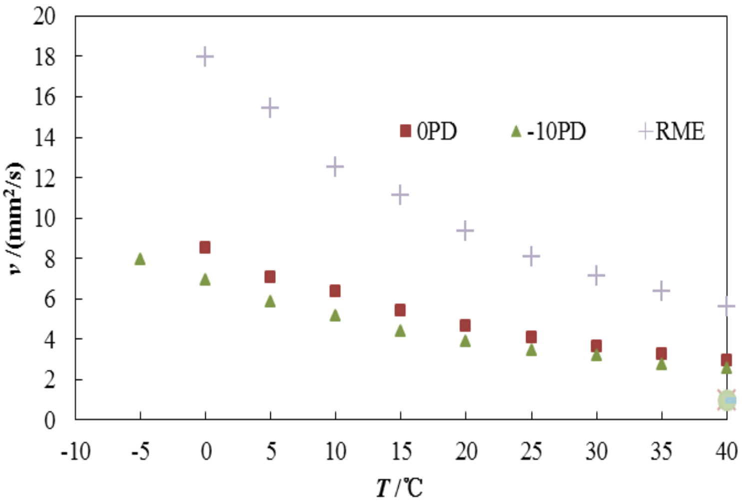


Fig. 2 The viscosity-temperature relationship of 0PD, -10PD and RME

From Fig. 2, we can see that comparing with petrodiesel fuel, kinematic viscosity of RME is higher, and as the temperature is decreased, RME viscosity increases rapidly. Thus, viscosity-temperature characteristic of RME 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: $v_t = 17.8699 - 0.5500t + 0.0062t^2$ R^2=0.9975.

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.

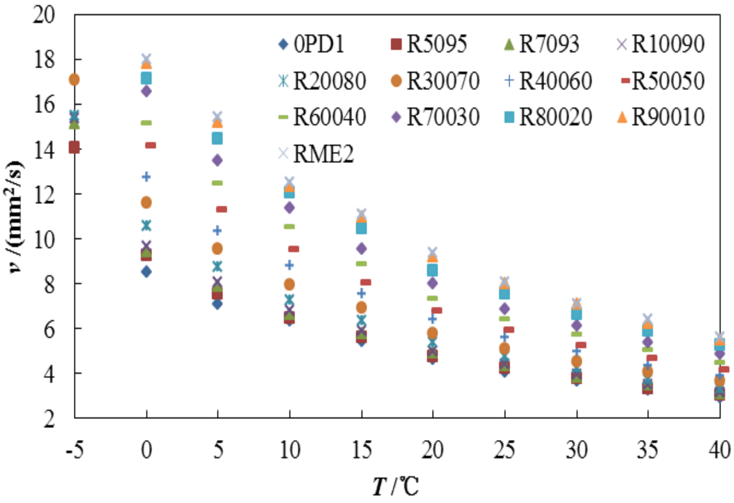
Based on lower viscosity and good viscosity-temperature characteristics of 0PD and -10PD (Fig. 2), an approach for reduce viscosity and enhance viscosity-temperature characteristics of RME is blending with 0PD or -10PD.

3.3 Viscosity-Temperature characteristics of RME/0PD and RME/-10PD

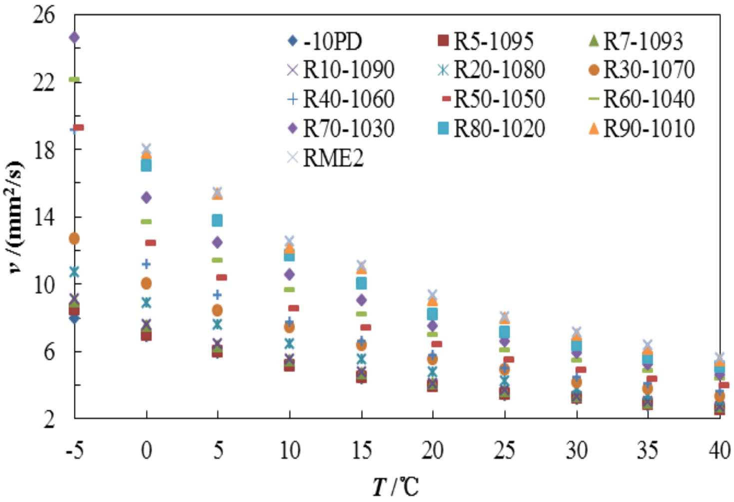
The kinematic viscosity (40 °C) and viscosity-temperature relationships of RME–0PD/-10PD blends are given in Fig. 3.

From Fig. 3, we can see that as the 0PD or -10PD ratio increases, RME/0PD or RME/-10PD kinematic viscosity decreases from RME 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 has shown good performance to predict the kinematic viscosity of the RME and its blends.



(a)



(b)

Fig. 3 The viscosity-temperature relationship of RME/0PD and RBME/-10PD

Table 3 Viscosity-temperature equations parameters of RME/0PD and RME/-10PD

Blend oil	Temperature Range/°C	*A*	*B*	*C*	R^2	Blend oil	Temperature Range/°C	*A*	*B*	*C*	R^2
$R_{5}0_{95}$	-5～40	10.4086	-0.4318	0.0066	0.9527	R_{5}-10_{95}	-5～40	7.1415	-0.2143	0.0026	0.9947
$R_{7}0_{93}$	-5～40	10.9717	-0.4700	0.0073	0.9398	R_{7}-10_{93}	-5～40	7.5636	-0.2340	0.0029	0.9966
$R_{10}0_{90}$	-5～40	11.1778	-0.4775	0.0074	0.9434	R_{10}-10_{90}	-5～40	7.6845	-0.2362	0.0029	0.9970
$R_{20}0_{80}$	-5～40	11.6800	-0.4718	0.0070	0.9648	R_{20}-10_{80}	-5～40	8.9954	-0.2798	0.0034	0.9976
$R_{30}0_{70}$	-5～40	12.8405	-0.5273	0.0079	0.9645	R_{30}-10_{70}	-5～40	10.4126	-0.3318	0.0040	0.9902
$R_{40}0_{60}$	0～40	12.4728	-0.3938	0.0046	0.9959	R_{40}-10_{60}	-5～40	13.4109	-0.6189	0.0100	0.9219
$R_{50}0_{50}$	0～40	13.8355	-0.4664	0.0058	0.9952	R_{50}-10_{50}	-5～40	14.1858	-0.6027	0.0092	0.9529
$R_{60}0_{40}$	0～40	14.9661	-0.4940	0.0059	0.9977	R_{60}-10_{40}	-5～40	15.9136	-0.6955	0.0108	0.9413
$R_{70}0_{30}$	0～40	16.3248	-0.5476	0.0067	0.9978	R_{70}-10_{30}	-5～40	17.6664	-0.7860	0.0122	0.9398
$R_{80}0_{20}$	0～40	17.0176	-0.5373	0.0062	0.9987	R_{80}-10_{20}	0～40	16.6887	-0.5516	0.0066	0.9972
$R_{90}0_{10}$	0～40	17.6505	-0.5417	0.0061	0.9971	R_{90}-10_{10}	0～40	17.6827	-0.5543	0.0063	0.9960

4. Conclusion

The above discussion shows that:

(1) RME is mainly composed of FAME of 16-24 even-numbered carbon atoms, and the mass fraction of SFAME ($C_{16:0}$-$C_{24:0}$) and UFAME ($C_{16:1}$-$C_{22:1}$, $C_{18:2}$-$C_{20:2}$ and $C_{18:3}$) is 12.42% and 87.46% respectively.

(2) The kinematic viscosity (40℃) of RME is 5.62 mm^2/s. RME 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 RME, RME/0PD and RME/-10PD at different temperature.

Acknowledgements

This research was supported by Anhui Provincial Natural Science Foundation (1408085ME109).

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