# Cold filter plugging point and viscosity - temperature characteristics of soybean oil biodiesel and improvement

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## Abstract

The chemical compositions, cold filter plugging point (CFPP) and viscosity - temperature characteristics of soybean oil methyl ester (SME) are investigated. Through blending with 0 petrodiesel (0PD) and -10 petrodiesel (-10PD), treating with Flow Fit K (FFK), the CFPP and viscosity - temperature characteristics are improved. The study shows that SME is mainly composed of fatty acid methyl esters (FAME), and the contents of saturated fatty acid methyl ester (SFAME) and unsaturated fatty acid methyl ester (UFAME) are 18.76% and 81.05% respectively. The CFPP and kinematic viscosity (40°C) of SME are -6 °C and 5.19mm2/s, respectively. Blending with 0PD and -10PD decreased the CFPP to -10 and -14°C in B60-B70 (SME/0PD) and B20 (SME/-10PD), respectively. With temperature decreasing, the kinematic viscosities of SME, SME/0PD and SME/-10PD increase. The lower the temperature, the more differenced the kinematic viscosities of SME and blending oil is. Treating with 1‰ (volume fraction) of Flow Fit K, the CFPP of blending oil decreased significantly. The CFPPs of B10 and B20 from -4 and -4°C to -18 and -17°C (SME/0PD), -9 and 14°C to -22 and -24°C (SME/-10PD).

## Keywords

Biodiesel, Soybean oil, Cold filter plugging point, Kinematic viscosity.

## 1. Introduction

Biodiesel is an alternative diesel fuel, mainly derived from vegetable oil and animal fat, provides an excellent solution to resolve problems related to environmental pollution and depletion of fossil based petroleum fuel[1]. The cold flow property (CFP) is an important performance indicator for diesel fuels, and is highly relevant both to maintaining a normal supply of fuel for diesel engines, and to the storage and transportation of diesel, at low temperatures. Since the high viscosity and poor CFP of biodiesel can readily result in the plugging of fuel pipes and fuel filters, and the impedance of a normal fuel supply during use, biodiesel is facing great impediments to its more widespread application as a fuel for compression ignition engines[2-3]. Cold flow properties of diesel fuel are generally characterized by the following parameters viz. cold filter plugging point (CFPP) and kinematic viscosity (KV), etc[4]. 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 chemical composition, CFPP, viscosity - temperature characteristics of soybean oil biodiesel. And impact of petrodiesel and cold flow improver (CFI) on SME CFPP and viscosity -

temperature characteristics. It can be expected to provide some help for the selection of petrodiesel and CFI ratios, that are beneficial for improving SME CFPP and viscosity - temperature characteristics.

## 2. Experimental

### 2.1 Materials

Soybean oil methyl ester (SME) is prepared by our laboratory, in line with GB/T 20828-2007 requirements. 0 petrodiesel (0PD), -10 petrodiesel (-10PD) is purchased from China Petroleum & Chemical Corporation. Flow Fit K (FFK) is purchased from Germany Liqui Moly.

### 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 Cold Filter Plugging Point Measured

The CFPP of oil samples is measured in accordance to SH/T 0248-2006, using the SYP2007-1 Cold Filter Plugging Point Tester (Shanghai BOLEA Instrument & Equipment Co., Ltd., China).

### 2.4 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

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

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

| SME | $C_{14:0}$ | $C_{16:0}$ | $C_{18:0}$ | $C_{20:0}$ | $C_{22:0}$ | $C_{24:0}$ | $C_{16:1}$ | $C_{18:1}$ | $C_{20:1}$ | $C_{22:1}$ | $C_{18:2}$ | $C_{20:2}$ | $C_{18:3}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Content | 0.22 | 12.35 | 4.86 | 0.62 | 0.43 | 0.28 | 0.18 | 34.24 | 0.92 | 1.88 | 37.71 | 0.10 | 6.02 |

Note: $C_{m:n}$ is the shorthand of fatty acid methyl ester; m means the carbon number of fatty acid; n means the number of C=C.

Table 1 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 SME are the fatty acid methyl ester (FAME) composed by 14-24 even number carbon atoms, and the mass fraction of saturated fatty acid methyl esters (SFAME) ($C_{14:0}$-$C_{24:0}$) and unsaturated fatty acid methyl esters (UFAME) ($C_{16:1}$-$C_{22:1}$, $C_{18:2}$-$C_{20:2}$ and $C_{18:3}$) is 18.76% and 81.05% 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 Cold Filter Plugging Point and viscosity - temperature characteristics

(1) Cold filter plugging point

As the temperature is decreased, SFAMEs within SME nucleate and form solid crystals which can clog or restrict flow through fuel filters or even become so thick that it can't flow. In China, the CFPP is an important indicator of biodiesel cold flow property. The lower CFPP, the better cold flow property of biodiesel is. The CFPP of SME, 0PD and -10PD is -6, -3 and -7°C, respectively.

(2) Viscosity - temperature characteristics

The viscosity-temperature relationships of SME, 0PD and -10PD are given in Fig. 1.

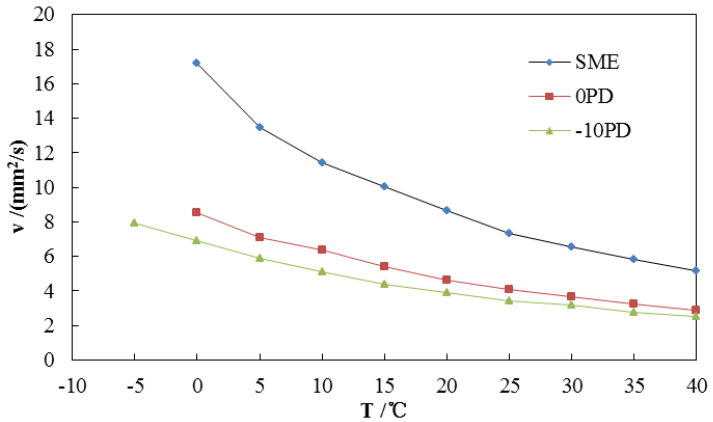



Fig. 1 The viscosity-temperature relationship of SME, 0PD and -10PD

The kinematic viscosity reflects the resistance of oil in the flow process. If the kinematic viscosity is too large, the friction may be increase, which is unfavorable for oil flow in the engine oil pipeline and filter. On the contrary, the kinematic viscosity is too small, the lubrication effect will reduce, which easy to cause mechanical wear and tear. Therefore, its range on the national standard (40°C) is from 1.9 mm2/s to 6.0mm2/s. The kinematic viscosity (40°C) of SME, 0PD and -10PD are 5.19, 2.91 and 2.53mm2/s.

With the temperature decreases, SME gradually appeared crystallization. At the same time, the curve of viscosity-temperature became steep, which reflects that their flow properties have become worst. At the same temperature, the kinematic viscosities of SME are greater than the 0PD and -10PD. The mainly reason is different structure. SME is mainly composed of 18 even-numbered C atoms FAME. 0PD and -10PD are mainly composed of long chain alkane of 10~17C atoms.

### 3.3 Improvement of CFPP and viscosity - temperature characteristics

3.3.1 Blending with 0PD and -10PD

(1) CFPP

The CFPPs of SME/0PD and SME/-10PD are shown in Fig.2.

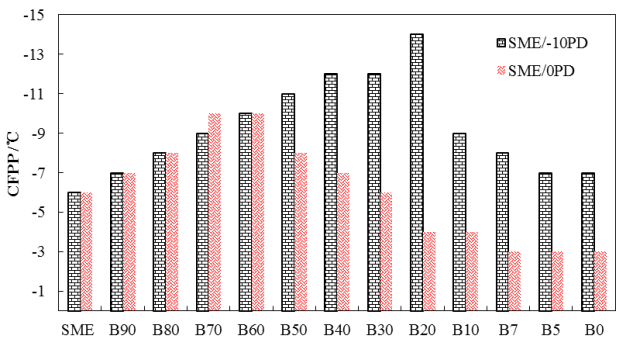
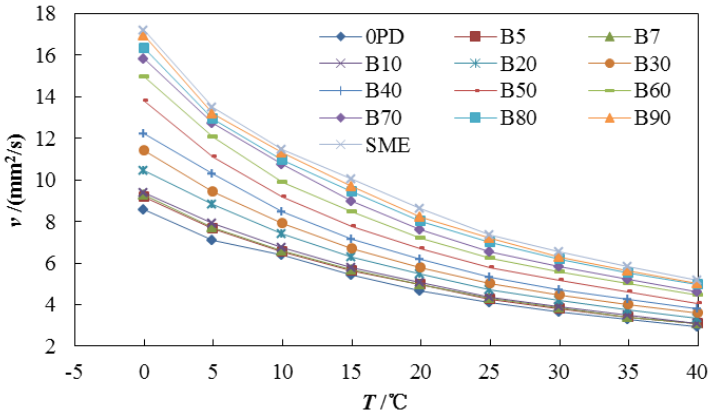



Fig. 2 The CFPP of SME/0PD and SME/-10PD

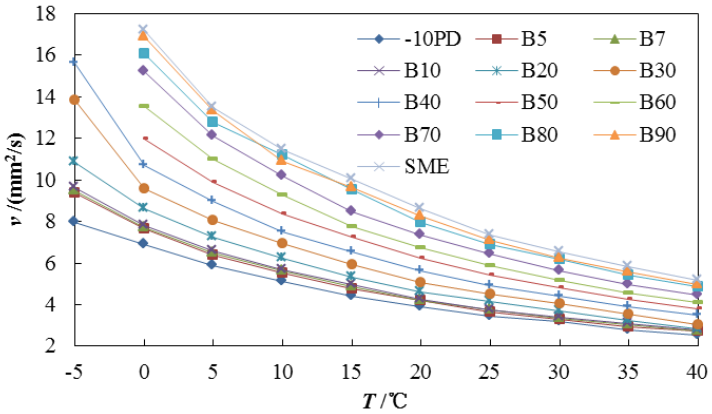
With increasing SME blending ratio, SME/0PD CFPPs decrease from -3 to -10°C with B0 – B60 (Bn is biodiesel blended with petro diesel, the n indicates the volume fraction of biodiesel in the blend.), staying at -10°C with B60 – B70, then increase to -6°C. And SME/-10PD CFPPs decrease from -7 to -14°C with B0 – B20, then increase to -6°C. It is chiefly because SME blending with 0PD and -10PD decrease SFAME content, which can resistant to form the 3D mesh "framework" structure at low temperature. By blending, the long chain SFAME of SME and long chain alkane of 0PD and -10PD can form a eutectic mixture, with B40 – B90 and B7 – B80, respectively. Therefore, the CFPPs of blending oil are lower than that of biodiesel and petrodiesel.

(2) Viscosity - temperature characteristics

The viscosity-temperature relationships of SME/0PD and SME/-10PD blends are given in Fig. 3.




(a) SME/0PD




(b) SME/-10PD

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

From Fig. 3, we can see that as the 0PD or -10PD ratio increases, SME/0PD or SME/-10PD kinematic viscosity decreases from SME 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.

3.3.2 Treating with FFK

(1) CFPP

The CFPPs of SME/0PD and SME/-10PD treating with FFK are given in Table 3.

The CFPP of SME is reduced from -6 to -8°C when add FFK in it. Meanwhile, the CFPPs of SME/0PD and SME/-10PD are decreased to -17 and -24 °C, respectively. It is mainly because that the crystallization behavior of FAME in oils is easily affected by CFI. FFK which absorbs on the surface of crystals can hold up the process, that crystals grow up and stuck together with each other, and then

that is difficult to form the three-dimensional network structure. It can be seen that treating with FFK can reduce the CFPPs of SME/0PD and SME/-10PD efficiently.

Table 3 The cold filter plugging point of SME/0PD and SME/-10PD without/with FFK

| Oil sample | | SME | 0PD | $S_{10}0_{90}$ | $S_{20}0_{80}$ | -10PD | $S_{10}$-$10_{90}$ | $S_{20}$-$10_{80}$ |
|---|---|---|---|---|---|---|---|---|
| No FFK, CFPP /°C | | -6 | -3 | -4 | -4 | -7 | -9 | -14 |
| With FFK | v‰ | 5 | 1 | 1 | 1 | 1 | 1 | 1 |
| | CFPP /°C | -8 | -21 | -18 | -17 | -26 | -22 | -24 |

Note: Sm0n is the shorthand of SME and 0PD blending oil; m indicates the volume fraction of SME in the blend; n indicates the volume fraction of 0PD in the blend. Sm-10n is the shorthand of SME and -10PD blending oil; m indicates the volume fraction of SME in the blend; n indicates the volume fraction of -10PD in the blend.

(2) Viscosity - temperature characteristics

The viscosity-temperature relationships of SME/-10PD without / with FFK are given in Fig. 4.

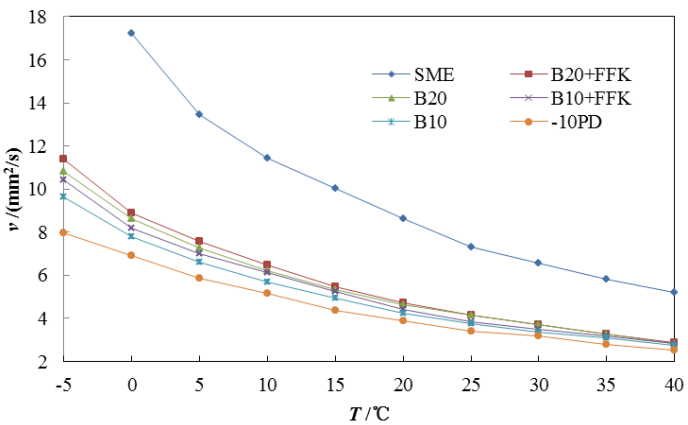



Fig. 4 The viscosity-temperature relationship of SME/-10PD without / with FFK

From Fig.4, we can see that small amount of FFK additives hardly affect viscosity - temperature characteristics of SME/-10PD blending oil.

## 4. Conclusion

Based on the results of this study, we conclude that:

The SME was mainly composed of FAME of 14-24 even-numbered C atoms. The mass fraction of SFAME and UFAME are 18.76% and 81.05%, respectively. The CFPP of SME is -6°C. SME has higher kinematic viscosity and unfavorable viscosity-temperature characteristics. And the kinematic viscosity of SME is 5.19mm2/s at 40°C.

Blending with petrodiesel can effectively reduce the CFPP and improve viscosity-temperature characteristics. The CFPPs of blending oil are -10°C and -14°C with B60-B70 (SME/0PD) and B20 (SME/-10PD), respectively. As the 0PD or -10PD ratio increases, blend oils kinematic viscosity increases slowly as temperature decreases, from SME to 0PD and -10PD.

Treating with CFI can also effectively reduce the CFPP. Adding with FFK decreases the CFPP of SME, S10090, S20080, S10-1090, S20-1080 from -6, -4, -4, -9, -14°C to -8, -18, -17, -22, -24°C, respectively.

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