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Measurement and correlation of viscosities and densities of methyl dodecanoate and ethyl dodecanoate at elevated pressures

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ABSTRACT

The density and viscosity data of two biodiesel components methyl dodecanoate and ethyl dodecanoate over the temperature range from (302–354) K and at pressures up to 15.2 MPa were reported. Experimental results show that the densities and viscosities of methyl dodecanoate and ethyl dodecanoate increase with the increase of pressure and decrease with the increase of temperature. The densities and viscosities of different fatty acid methyl esters and fatty acid ethyl esters were compared to investigate the effect of carbon number. Tait equation and Andrade-Tait model were used to model the measured densities and viscosities of methyl dodecanoate and ethyl dodecanoate.

1. Introduction

The oil crisis and the deteriorating environment caused by the consumption of fossil fuels make the world aware of the importance of finding alternative fuels which are clean and renewable [1]. Among the proposed alternative fuels, biodiesel is widely regarded as one of the most appropriate fuels for changing diesel engine with the advantage of higher cetane number, low greenhouse gas emission, renewability and biodegradability [2]. Thermophysical properties of biodiesel have a vital influence on the engine performance. For example, the density of biodiesel has an important influence on the fuel mass injected into the engine and the viscosity of biodiesel is related to the size of the droplets in the fuel injection process and the lubrication of injector and pump [3]. However, few data have been reported for the densities and viscosities of biodiesels as well as their components over a wide range of pressure [3–16], especially for viscosities. Only Habrioux et al. [3,16] have measured the viscosity data of methyl decanoate, ethyl decanoate, methyl tetradecanoate, and ethyl tetradecanoate using a falling-body viscometer and a quartz crystal resonator viscometer over the temperature range from 293 K to 353 K and at pressures up to 200 MPa. And our group [11] has determined the viscosities of ethyl heptanoate and ethyl octanoate at temperatures from 303 K to 353 K and at pressures from 0.1 to 15 MPa.

Methyl dodecanoate and ethyl dodecanoate are both the main components of coconut oil and babassu oil [17–19], but the density and viscosity data of them is insufficient at present. In this work, new density and viscosity data for methyl dodecanoate and ethyl dodecanoate at pressures from 0.1 to 15.2 MPa and at temperatures from 302 K to 354 K are presented. In addition, Tait equation and Andrade-Tait model were used to correlate the measured data of density and viscosity, respectively.

2. Experimental section

Table 1 shows the characteristics of methyl dodecanoate and ethyl dodecanoate used in this work including the information about source, chemical formula, purity, water content in mass fraction and CAS number. They were used without further purification.

As shown in Fig. 1, the viscosity experimental system is based on the capillary method [11,20]. The experimental system consists of a plunger-type pump (Scientific Systems 1500), a Siemens flowmeter (MASS 2100 DI 1.5 + MASS 6000) with accuracy of 0.1% for flow rate, two thermostatic baths whose temperatures were measured using two Fluke platinum resistant thermometers (5608) with expanded uncertainties of 0.02 K (k = 2, degree of confidence is 95%), two Rosemount pressure transmitters (3051S, 20 MPa) with expanded uncertainties of 5 kPa (k = 2), a Rosemount differential pressure transmitter (3051S, 60 kPa) with an expanded uncertainty of 0.015 kPa (k = 2), a counterbalance valve, a preheater and experimental cell. The pressure in the system was controlled by the plunger-type pump and the counterbalance valve, and measured by the pressure transmitters. The temperatures of experimental cell and Siemens flowmeter were controlled by two thermostatic baths. The plunger-type pump and the Siemens flowmeter were used to control and measure the flow rate of fluid, respectively, while the differential pressure transmitter was used to measure the pressure drop of fluid through the capillary tube.

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Table 1
Characteristics of chemicals used in this work.

Name	Chemical formula	Source	Mass fraction purity[a]	Water content in mass fraction[b]	CAS
Methyl dodecanoate	$C_{13}H_{26}O_2$	Sigma-Aldrich	0.99	0.0006	111 − 82-0
Ethyl dodecanoate	$C_{14}H_{28}O_2$	Sigma-Aldrich	0.99	0.0005	106 − 33-2

[a] Stated by the supplier.
[b] Measured with a KLS701 Karl Fischer titrator provided by Zibo Kulun Analysis Instrument Co., Ltd.

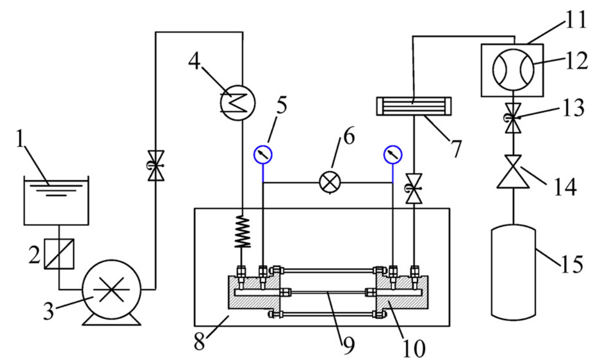

Fig. 1. Schematic diagram of experimental apparatus : 1, Sample; 2, Filter; 3, Plunger-type pump; 4, Preheater; 5, Pressure transmitter; 6, Differential pressure transmitter; 7, Condenser; 8, Thermostatic bath; 9, Capillary tube; 10, Experimental cell; 11, Thermostatic bath; 12, Flowmeter; 13, Needle valve; 14, Counterbalance valve; 15, Collecting bottle.

Besides, the length and inner radius of the capillary tube were calibrated to be 511 mm and 0.189 mm, respectively. The Siemens flowmeter can also be used to measure the density of fluid with an expanded uncertainty of 2 kg·m^{-3} (k = 2) by measuring the oscillation period of the vibrating tube inside the Mass 2100 DI 1.5 sensor. When the temperature and pressure of fluid in the Mass 2100 DI 1.5 sensor were stable, the density of fluid was read using Mass 6000 transmitter.

For a laminar flow in pipe, the dynamic viscosity of fluid η can be expressed as follow

$$\eta = \frac{\pi\rho R^4 \Delta p}{8qL} \tag{1}$$

Where L and R are the length and inner radius of the capillary tube, respectively; Δp is the pressure difference between the capillary tube inlet and outlet; q is the mass flow rate of the sample and ρ is the density.

Considering the change in the geometrical size of the capillary tube and kinetic energy correction, Eq. (1) is rewritten as [18]

Table 2
Experimental density data of methyl dodecanoate and ethyl dodecanoate[a].

T/K	p/MPa	ρ/(kg·m^{-3})	T/K	p/MPa	ρ/(kg·m^{-3})
Methyl dodecanoate			Ethyl dodecanoate		
303.10	0.10	861.8	303.06	0.10	853.9
303.11	3.01	863.7	303.07	3.05	856.6
303.13	6.03	865.7	303.26	5.99	858.4
303.16	9.05	867.9	303.22	9.02	860.5
303.20	12.03	869.8	303.23	11.99	862.5
303.20	15.04	871.7	303.24	15.03	864.5
312.95	0.10	853.4	313.08	0.10	846.3
313.11	3.03	855.3	313.08	3.01	848.3
313.08	6.05	857.4	313.10	5.98	850.4
313.06	9.04	859.2	313.15	9.03	852.6
313.12	12.03	861.2	313.17	12.01	854.4
312.95	15.05	863.4	313.26	15.03	857.5
323.05	0.10	845.5	323.14	0.10	838.3
323.17	3.03	847.4	323.09	3.05	840.8
323.30	6.05	849.3	323.17	5.98	842.9
323.33	9.05	851.6	323.17	8.98	845.0
323.27	12.04	853.8	323.17	11.99	847.0
323.40	15.02	855.9	323.18	15.02	849.0
333.15	0.10	837.8	333.17	0.10	830.8
333.15	3.04	840.3	333.17	3.01	833.0
333.15	6.04	842.3	333.07	6.00	835.8
333.18	9.05	844.7	333.20	9.04	838.1
333.16	12.02	846.9	333.17	12.04	840.3
333.14	15.03	849.0	333.15	15.04	842.5
343.18	0.10	829.4	342.95	0.10	823.2
343.22	3.02	831.9	343.00	3.00	825.3
343.22	6.02	833.9	343.19	5.98	828.3
343.21	9.04	836.6	343.28	9.02	830.8
343.19	12.06	838.5	343.19	11.98	832.8
343.19	15.05	841.1	343.19	15.02	834.9
353.27	0.10	821.6	353.15	0.10	815.3
353.28	3.04	824.4	353.15	3.05	818.4
353.23	6.05	826.8	353.20	6.03	820.9
353.26	9.03	829.5	353.19	9.02	823.2
353.18	12.03	831.6	353.18	12.01	825.6
353.16	15.04	834.1	353.19	15.02	827.9

[a] Expanded uncertainties U are U (T) = 0.02 K, U (p) = 5 kPa, U (ρ) = 2 kg·m^{-3}. The level of confidence is 0.95 (k = 2).