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Surface tensions of petro-diesel, canola, jatropha and soapnut biodiesel fuels at elevated temperatures and pressures

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HIGHLIGHTS

- ▶ Surface tensions of three biodiesel fuels and diesel were measured at elevated temperatures and pressures.
- ▶ Surface tensions were measured up to 473 K and 7 MPa for all biodiesel samples.
- ▶ Surface tensions of three biodiesel were measured at elevated temperatures and pressures.
- ▶ The surface tension of diesel and biodiesel fuels showed a linear relationship with temperatures and pressures.

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ABSTRACT

This study presents the experimental results of surface tension measurements of diesel as well as canola, jatropha and soapnut biodiesel fuels. A high pressure pendant drop equipment (PD-E 1700) and drop shape analysis (DSA 100 V1.9) were used to measure the equilibrium surface tension of diesel and biodiesel fuels at elevated temperatures and pressures. Surface tension tests were carried out in a nitrogen environment. The surface tension of diesel and biodiesel fuels showed a linear relationship with temperatures and pressures. A regression model was also developed using the measured data from the tests for each fuel.

1. Introduction

Surface tension is one of the important physical properties of liquid fuels affecting the atomization in a diesel engine. Enhanced atomization and proper air–fuel mixing helps complete combustion, increases engine efficiency and reduces pollutant emissions [1]. A balanced value of viscosity, density and surface tension is required for proper atomization in direct injection engines [2]. Some previous studies in compression ignition engines have indicated that biodiesel fuels from different feedstock sources have different atomization properties [3,4]. Such differences in atomization properties are potentially due to the difference in their physical properties including density, viscosity and surface tension. These properties greatly affect the droplet formation [2,5]. It has also been reported that the high surface tension of the liquid fuel makes the droplet formation more difficult [6] and leads to inefficient atomization [7]. The long fatty acid chain hydrocarbons and unsaturated bonds in biodiesel fuels make the surface tension to increase [6]. The surface tensions of pure biodiesel fuels can be reduced by using the blends of pure biodiesel with diesel fuels at different ratio [2,8]. Data for blends of jatropha and soapnut biodiesel with petro diesel are given elsewhere [9].

Among the various approaches to estimate the surface tensions of biodiesel fuels, the parachor method is one of the basic methods commonly used. Allen et al. [5] and Knotts et al. [10] predicted the surface tensions of different biodiesel fuels based on their fatty acid composition in mass percentage and their parachors. The parachor values were assigned to groups of atoms based on linkage and composition by Gibling [11,12]. Shu et al. [6] used a topological index from the molecular structure to predict the surface tension of biodiesel fuels. The topological index method uses a combination of the distance matrix and adjacent matrix of the molecular structures. There are other thermodynamic correlations [13–15] and equation of state models [16,17] used to describe the surface tension properties of fluids. One of the equation of state models most commonly used to calculate the surface tension of pure alkanes and their mixtures with water was developed using a cubic equation of state as a reference equation of state [18]. Density gradient theory [19,20] and perturbation theory [21] have

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also been used to estimate surface tension. Lu et al. [22] used the density functional theory to predict the surface tensions of fluids.

Stalder et al. [23] presented a method for surface tension and contact angle measurement using low bond axisymmetric drop shape analysis. Joshi [24] measured the surface tensions of canola biodiesel and its blends from 293 to 533 K using the pendant drop method, analyzed using the Axisymmetric Drop Shape Analysis Profile (ADSA-P). Tate [25] measured the surface tensions of canola biodiesel, soybean biodiesel and fish oil biodiesel using pendant drop tensiometry. Some previous studies [24,26] have also described some methods to estimate the surface tensions of biodiesel and its blends.

In this work, high pressure pendant drop equipment was used to measure the surface tension of petro-diesel, canola, jatropha and soapnut biodiesel fuels from atmospheric pressure to 7 MPa and from room temperature to 473 K, the maximum temperature allowed by the equipment.

The surface tension was measured based on the principle that a drop hanging from a syringe needle, which is in hydrochemical equilibrium, assumes a characteristic shape and size from which the surface tension can be calculated. The Young–Laplace equation, used to derive the surface tension for a pendant drop in hydrochemical equilibrium is presented below in Eq. (1).

$$\Delta p = \sigma * \left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad (1)$$

where r_1 and r_2 are the principal radii of curvature at any point of the drop, σ is the surface tension, Δp is the difference in pressure between the outside of the pendant drop and its inside.

The surface tension of the pendant oil drop surrounded by either air or nitrogen phase is determined by using the Young–Laplace equation of capillarity by finding the best numerically calculated surface profile to fit the physically observed drop profile. It is considered one of the most accurate techniques for a large range of temperatures and pressures [24].

2. Experimental methods

A commercial canola biodiesel produced by Milligan Bio-Tech (Saskatchewan, Canada) was used for measurement of the surface tension of canola methyl ester. Neat jatropha oil sample was obtained from Aaditya Aromedic & Bio Energies Pvt. Ltd., Tarsadi, Gujarat State of India. Soapnut oil sample was purchased from Satya Sai International Pvt. Ltd. in Western Nepal. The jatropha and soapnut oils were transesterified into methyl ester biodiesel fuels in the Dalhousie University Laboratory. The fatty acid composition of canola, jatropha and soapnut biodiesel are presented in Table 1 [27]. The three biodiesel fuels used for this work were characterized as per ASTM fuel quality standards and are summarized elsewhere [27]. The characteristics of the petro-diesel are also given in the same reference.

2.1. Apparatus

High pressure pendant drop equipment (PD-E 1700) and drop shape analysis (DSA 100 V1.9) were used to measure the dynamic and equilibrium surface tension of different biodiesel blends at various temperatures and pressures. The PD-E-1700 built by Eurotechnica was used in this work and is shown in Fig. 1. The DSA V1.9 is a drop shape analysis software built by KUSS (Germany). The DSA V1.9 software acquires and analyzes the picture of the pendant drop as shown in Fig. 2.

The major component of this system is a high-pressure cell with windows on two sides. The maximum operating pressure and temperature of this cell is 69 MPa and 473 K respectively. The drop shape analysis DSA100 V1.9 consists of a high-resolution CCD camera with a light source. The high-pressure cell is located between the CCD camera and light source. In this method, a pendant oil drop is formed on the tip of the stainless-steel needle installed at the top of the pressure cell in an air or nitrogen phase. With a digital image acquisition system from DSA100 V1.9, a digital image is acquired. The software requires the density of the test liquid (petro-diesel and biodiesel) and density of the gas phase (either air or nitrogen) surrounding the test liquid. The densities of the liquids at the respective temperatures and pressures have been reported elsewhere [27]. The densities of the surrounding gases were computed assuming the ideal gas law.

Fig. 1. High-pressure pendent drop equipment (PD-E 1700) and drop shape analysis (DSA100 V1.9).

Table 1
Fatty acid composition of canola, jatropha and sopanut biodiesel obtained from GC analysis [27].

Type of fatty acids	Carbon chain	Canola biodiesel fatty acid content (%)	Jatropha biodiesel fatty acid content (%)	Soapnut biodiesel fatty acid content (%)
Lauric acid	C12:0		0.31	
Myristic	C14:0	0.242		
Palmitic	C16:0	4.77	13.38	4.67
Palmitoleic	C16:1	0.363	0.88	0.37
Stearic	C18:0	1.978	5.44	1.45
Oleic	C18:1	60.284	45.79	52.64
Linoleic	C18:2	20.029	32.27	4.73
Linolenic	C18:3	8.731		1.94
Arachidic	C20:0	0.582		7.02
Ecosenoic	C20:1	1.283		23.85
Behenic acid	22:00	1.45		1.45
Erucic acid	22:01	1.09		1.09
Lignoceric acid	C24:0	0.117		0.47
Others		1.621	1.93	0.32
Total		100	100	100