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Research article

Two-term power models for estimating kinematic viscosities of different biodiesel-diesel fuel blends

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ABSTRACT

Corn and hazelnut oil biodiesels were produced by using methanol (CH_3OH) and sodium hydroxide (NaOH), and blended with commercially available Ultra Force Euro diesel fuel at the volume ratios of 5, 10, 15, 20, 50 and 75%. The kinematic viscosities of the prepared blends at temperatures of 10, 20, 30 and 40 °C were measured by following DIN 53015 standard. The effects of temperature and biodiesel fraction on the kinematic viscosities of the blends were assessed. New two-term power models were derived to estimate kinematic viscosities of the blends. The models were also fitted to kinematic viscosities of different biodiesel-diesel fuel blends given in literature, and compared to the previously presented models to determine their validities.

1. Introduction

Currently, more than 80% of the world's energy needs have been met by fossil fuels [1]. However, their fluctuating prices and rapid declining known reserves, and environmental concerns about air pollution [2,3] have focused searches on alternative fuels. Among the alternatives, biodiesel is gaining worldwide attention and considered to be one of the most practical energy sources for diesel engines which have been used widely in the transportation, construction work and power generation due to their high thermal efficiency and durability [1,4].

Biodiesel is defined as a mixture of long chain fatty acid alkyl esters, which can be produced from various edible and non-edible feedstock through the transesterification reaction with short-chain alcohols (methanol or ethanol) in the presence of basic (sodium hydroxide, potassium hydroxide and sodium ethoxide) or acidic catalyst (sulfuric, sulfonic, and heteropoly acid, and Purolite®PD206) [5–9]. It has many competitive physiochemical properties compared to diesel fuel such as better ignition quality due to higher cetane number, higher density and lubricity, faster biodegradability, greater safety due to their higher flash point temperature, non-toxic character, less sulfur content, renewable nature and lower exhaust emissions of carbon monoxide (CO), unburned hydrocarbons (HC) and particulate matter [2,10–13]. These properties of biodiesel make it an ideal fuel for diesel engine in a way. However, there are also some shortcomings like lower energy content and volatility, higher viscosity, price, iodine number and NO_x emissions, and poor cold flow properties [14–19]. Blending is one of the methods to overcome these shortcomings. For example, density and viscosity of the biodiesel can be improved by mixing with diesel fuel. Recently, a lot of studies have been carried out to investigate the variations of biodiesel properties after blending with diesel fuel [20]. Gülüm and Bilgin [10] investigated the variations of densities, flash point temperatures and higher heating values of corn oil biodiesel-Ultra Force Euro diesel fuel blends. The effects of biodiesel percentage in blend and temperature on densities of the blends were assessed. The authors also proposed one- and two-dimensional models to predict these fuel properties. Geacai et al. [21] measured the viscosities of binary blends of biodiesel + diesel fuel, biodiesel + benzene and biodiesel + toluene in the temperature range of 293.15–323.15 K. The Grunberg–Nissan, Wilke and McAllister equations were used to correlate the changes of viscosities with biodiesel composition for blends, while only Andrade equation was used for relationship between viscosity and temperature. An equation based on Eyring's theory of absolute reaction rates was also derived to estimate the kinematic viscosities of biodiesel blends at various temperatures and compositions. In the study performed by Sarin et al. [22], palm oil biodiesel was blended with Jatropha and Pongamia biodiesels to improve the low temperature flow properties like cloud point and pour point temperatures. Also, the effect of fatty acid methyl ester composition in the blended biodiesels (palmitic acid methyl ester, total unsaturated fatty acid methyl ester) on cloud point and pour point temperatures were investigated, and linear correlations between them were determined. Baroutian et al. [20] determined densities and dynamic viscosities of the binary mixtures of methyl esters + ethyl esters and ternary blends of methyl esters + ethyl esters + diesel fuel at various compositions and temperatures. The methyl and ethyl esters were

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Nomenclature and units

a, b, c	regression constants
B5, B10, B15, B20, B50, B75	biodiesel-diesel fuel blends
B100	neat biodiesels
COB	neat corn oil biodiesel
D	neat diesel fuel
HOB	neat hazelnut oil biodiesel
m_{total}	mass of the pycnometer filled with biodiesel (g)
R	correlation coefficient
t	falling time of the viscometer ball (s)
T	temperature (°C)
$w_1, w_2, w_3, \ldots, w_n$	uncertainties of independent variables
$w_\sim$	dimensionless uncertainty
$x_1, x_2, x_3, \ldots, x_n$	independent variables
X	biodiesel fraction (v/v)

Greek symbols

μ	dynamic viscosity (g/m·s≡mPa·s≡cP)
ν	kinematic viscosity (mm^2/s≡cSt)
ρ	density (kg/m^3), (g/cm^3)

produced through transesterification of palm and jatropha oils. The results revealed that viscosities and densities of binary and ternary blends decreased nonlinearly and linearly with temperature, respectively. Moreover, one- and two-dimensional models were proposed to represent the changes of densities and viscosities of the mixtures with temperature and volume fraction.

In this study, (1) corn and hazelnut oil biodiesels (COB, HOB) were produced by using CH_3OH and NaOH, (2) these biodiesels were blended with commercially available Ultra Force Euro Diesel (D) at the volume ratios of 5, 10, 15, 20, 50 and 75%, (3) kinematic viscosities of COB-D and HOB-D blends were measured at different temperatures appropriate to the average climate conditions (10, 20, 30, 40 °C) according to DIN 53015 standard, (4) the uncertainty analysis was performed to determine reliability of the measurements, (5) the effects of temperature and biodiesel fraction on the kinematic viscosities of the blends were assessed, (6) new two-term power models as a function of temperature (T) or biodiesel fraction (X) were proposed to estimate kinematic viscosities of these blends, and (7) the derived models were compared with the previously published common models for showing their validities.

2. Experimental methods

2.1. Biodiesel production

In this study, all reagents (methanol, sodium hydroxide and anhydrous sodium sulfate) were purchased from Merck and were of about 99% purity. Methanol, pure grade sodium hydroxide and refined corn and hazelnut oils which are agricultural products at Black Sea region of Turkey were used to produce biodiesels. The reaction parameters for transesterification of corn oil were determined as 0.90% catalyst concentration, 50 °C reaction temperature, 60 minute reaction time and 9:1 alcohol/oil molar ratio, while the reaction parameters for transesterification of hazelnut oil were determined as 1.00% catalyst concentration, 50°C reaction temperature, 60 minute reaction time and 9:1 alcohol/oil molar ratio [23,24]. Transesterification reaction was carried out in a 1 L flat-bottomed reaction flask, equipped with a magnetic stirrer heater, thermometer and spiral reflux condenser. Isolab pycnometer and top loading balance with an accuracy of ±0.01 g were used to measure density. Before starting the reaction, NaOH was dissolved in methanol by stirring in a small flask, and this alcohol/catalyst mixture was added into the corn or hazelnut oil that was formerly warmed. Then, the final mixture was mixed with stirring by means of the magnetic stirrer heater. After the transesterification, lower phase (glycerol) was removed by a separating funnel, while upper one (biodiesel) was washed with warm distilled water at about 60 °C. The volumetric amount of distilled water to wash is about 50% of produced biodiesel. This process was repeated several times until the pH is neutral. The washed biodiesel was distilled under vacuum distillation to remove water and methanol. Then, it was dried over anhydrous sodium sulfate (left over night) and finally filtered using qualitative filter papers.

2.2. Density measurement

The densities of the produced neat biodiesels (COB and HOB) and their blends with diesel fuel (D) were determined in accordance with ISO 4787 standard as [25]:

$$\rho_{biodieselorblends} = \frac{m_{total} - m_{pycnometer}}{m_{water}} \rho_{water}. \quad (1)$$

Details of the measurements were given in [10].

2.3. Dynamic viscosity measurement

The dynamic viscosities at 10, 20, 30 and 40 °C were determined in accordance with DIN 53015 standard [26] by using Eq. (2) and making measurements by means of the Haake Falling Ball Viscometer, Haake

Table 1
Some fuel properties of diesel fuel and produced COB and HOB, and corresponding standard values for biodiesel.

Properties	Unit	D	COB	HOB	EN14214	ASTM-D6751
Viscosity at 40 °C	mm^2/s	2.700	4.095	4.128	3.50–5.00	1.90–6.00
Density at 15 °C	kg/m^3	832.62	876.37	873.06	860–900	[a]
Flash point	°C	63	169	177	≤101	≤130
CFPP	°C	−6.0	−5.0	−6.0	<+5 (summer) <−15 (winter)	[a]
Average molecular mass	g/mol	169.883[b]	292.870[c]	293.800[c]	–	–
Typical formula	–	$C_{12.31}H_{21.975}$[d]	$C_{18.77}H_{35.16}O_2$[c]	$C_{18.76}H_{35.56}O_2$[c]	–	–
HHV	kJ/kg	45,950	39,930	39,883	[a]	[a]

[a] Not specified.
[b] Calculated from typical formula.
[c] Calculated from fatty acid distribution.
[d] Calculated from HHV and Mendeleev's formula.