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Measurements and empirical correlations in predicting biodiesel-diesel blends' viscosity and density

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HIGHLIGHTS

- Density-biodiesel content variation is well correlated by linear model.
- Exponential equation is the best model for density-temperature variation.
- Rational model is the most proper one to predict viscosities of fuel blends.
- Power model is the best one to characterize viscosity vs. temperature variation.
- Two-term power model better correlates density-viscosity variation.

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ABSTRACT

One of the attempts to limit the use of fossil fuels in automobiles is to replace them partially or totally with clean and renewable fuels. Among renewable fuels, biodiesel has emerged as an important alternative to petroleum diesel fuel. Therefore, in this study, first, biodiesel was produced from hazelnut oil, which is agricultural product at Black Sea region of Turkey, by means of transesterification reaction. The produced biodiesel was blended with Ultra Force Euro diesel fuel at the volume ratios of 5, 10, 15, 20, 50 and 75% which are called as B5, B10, B15, B20, B50 and B75 as usual, respectively. Second, the densities and kinematic viscosities of each blends were measured at average climate conditions as 10, 20, 30 and 40 °C by following international ISO 4787 and DIN 53015 standards. Finally, new models were derived through the least squares regression method for density-temperature, kinematic viscosity-biodiesel fraction, kinematic viscosity-temperature and kinematic viscosity-density relationships, and compared with well-known models previously published in literature to determine the well-matched models.

1. Introduction

Fossil fuels such as natural gas, petroleum products (conventional diesel and gasoline), coal etc. have been meeting most industrial and commercial demands for decades [1]. However, in recent years, because of increasing concerns of global warming and air pollution, depletion of world-wide petrol reserves for increasing of industrialization and motorization, and rising prices of fossil fuels, alternative and renewable transportation fuels such as hydrogen, ethanol, dimethyl-ether, biodiesel etc. have acquired more and more attention in worldwide [2–6]. Among these fuels, biodiesel, which is defined as a mixture of mono alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats [7,8], is a sustainable fuel as a result of applicability to diesel engine without significant modifications [9,10]. Biodiesel has many benefits such as non-toxic, non-aromatic and non-sulfur content, better biodegradability and lubricity, lower particulate matter (PM), carbon monoxide (CO) and unburned hydrocarbon emissions (UHC), and higher cetane number (CN) and flash point temperature (FP), compared to diesel fuel [11–16]. In addition, biodiesel is completely miscible with diesel fuel, allowing to blend in any proportion [17,18]. For example, commercial biodiesel-diesel fuel blends containing up to 7% v/v of biodiesel (in some countries even 10% v/v) are currently used in the European Union, but efforts are made to increase the biodiesel content to 20% [19]. Although these properties make biodiesel an ideal fuel for diesel engines, it has also some disadvantages such as lower heat of combustion and volatility, higher viscosity, NO_x emissions, price, cloud and pour point temperatures [20,21].

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Nomenclature

a, b, c, d	Regression constants
B1, B5, B10, B15, B20, B25, B50, B60, B75	Biodiesel-diesel fuel blends
CFPP	Cold filter plugging point (°C)
D	Neat Ultra Force Euro diesel
D2	No. 2 diesel fuel
CN	Cetane number
HHV	Higher heating value (kJ/kg)
HOB	Neat hazelnut oil biodiesel
IV	Iodine value
K_{ball}	Coefficient of the viscometer ball (mPa·s·cm^3/g·s)
m_{total}	Mass of the pycnometer filled with biodiesel (g)
R	Correlation coefficient
SMEB	A second natural soybean oil methyl ester
SN	Saponification number
t	Falling time of the viscometer ball (s)
T	Temperature (°C)
ULSD	Ultra low sulfur diesel
$w_1, w_2, w_3, \ldots, w_n$	Uncertainties of independent variables
$\tilde{w}$	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)

Viscosity is one of the most significant fuel properties because it affects atomization quality, the size of fuel droplets and jet penetration, all of which affect the quality of combustion [19]. For utilization in engines, the fuel viscosity should be limited between upper and lower limits. It must be low enough to flow freely at its lowest operational temperature while too low viscosity can cause leakage in the fuel system. High viscosity causes poor fuel atomization and incomplete combustion, increases engine deposits, requires more power to pump the fuel, and causes more problems in cold weather, as viscosity increases with decreasing temperature. Viscosity also affects injectors and fuel pump lubrications [19].

The density is also a very important fuel property, since other crucial engine performance parameters such as cetane number and heating value have been correlated against it [22]. Diesel fuel injection systems measure fuel by volume, so changes in the fuel density will influence engine output power due to a different mass of fuel injected to combustion chamber [23]. In addition, the variation of density also affects the fuel spray characteristics during fuel injection and combustion in cylinder [22], so that they influence the combustion characteristic and exhaust emissions [23].

Differences in the chemical nature of biodiesels (mixture of mono-alkyl esters) and conventional diesel fuel (mixture of paraffinic, naphthenic and aromatic hydrocarbons) result in differences in basic properties of biodiesel-diesel fuel blends such as density, viscosity, cetane number, heating value etc., affecting engine performance, combustion characteristics and pollutant emissions [24]. As the use of biodiesel-diesel fuel blends becomes attractive in diesel engines, researchers have shown interest in modeling of spray and combustion processes. They often use the properties as input data in their thermodynamic or dimensional engine modeling studies. However, it may not be practical at every turn to make measurements of them for each blending ratio and/or temperature in any modeling study. Therefore, regression equations have been used to satisfy the need for quick accessibility to property data. Some studies reporting these equations are summarized as follows. Tesfa et al. [22] investigated effects of temperature and biodiesel fraction on densities and viscosities of rapeseed, corn oil and waste oil biodiesels-diesel fuel blends, and developed new correlations between density and viscosity for the blends (0B, 5B, 10B, 20B, 99 50B, 75B and 100B). Nita et al. [25] measured densities, viscosities and refractive indices of biodiesel-diesel and biodiesel-benzene mixtures at 298.15 K. The densities and viscosities of prepared mixtures were estimated using Kay's mixing rule and Grunberg-Nissan modified equations, respectively. Fahd et al. [26] investigated densities, dynamic viscosities and higher heating values of waste cooking palm oil biodiesel-diesel blends (B20, B40, B60 and B80) under varying temperature and blend ratio. 1st order and exponential equations as a function of temperature were used to predict densities and dynamic viscosities for each of the fuel blends, respectively. In the study conducted by Barabas [27], for predicting densities of rapeseed oil biodiesel-diesel-bioethanol and used cooking oil biodiesel-diesel-bioethanol blends, 2 × 15 ternary mixtures were prepared. Four new mixing rules were elaborated for density values of the blends. Temperature-density variations were modeled by linear and polynomial regressions. In the study done by Alptekin and Canakcı [23], biodiesels produced from six different vegetable oils (sunflower, canola, soybean, cottonseed, corn and waste palm oils) were blended with commercially available two different diesel fuels (shell extra diesel and normal diesel) at the volume ratios of 2, 5, 10, 20, 50 and 75%. A mixing equation, originally proposed by Arrhenius and described by Grunberg and Nissan, was used to predict viscosities of the blends. Pratas et al. [28] reported new experimental density data for different biodiesels in the temperature range of 278.15 to 373.15 K and at atmospheric pressure. Three versions of Kay's mixing rules and two versions of the GCVOL model (group contribution volume) were investigated to predict biodiesel densities.

Although literature presents lots of prediction models to estimate physicochemical properties of different diesel-biodiesel blends, there will be always need for new models for better characterizing the properties with higher accuracy compared to the existing models and checking them with different biodiesel-diesel fuel blends. Therefore, in this study, the authors (1) proposed new linear, exponential, two-term power, rational and hyperbolic models, (2) tried them on not only produced hazelnut oil biodiesel but also the other existing biodiesel-diesel fuel blends, and (3) compared to the models proposed in other studies given in the existing literature.

2. Materials and methods

2.1. Biodiesel production

In this study, methanol, potassium hydroxide and anhydrous sodium sulphate were of about 99 purity and purchased from Merck. Since hazelnut is one of the important agricultural plant in the Black Sea region of Turkey, refined hazelnut oil was selected to produce biodiesel. Transesterification reaction parameters were selected as follows: % 1.25 catalyst concentration, 60 °C reaction temperature, 60 min reaction time and 9:1 alcohol/oil molar ratio after a detailed parametric investigation [29].