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THERMOPHYSICAL PROPERTIES OF CASTOR OIL (*RICINUS COMMUNIS* L.) BIODIESEL AND ITS BLENDS

PROPIEDADES TERMOFÍSICAS DE BIODIESEL DE ACEITE DE RICINO (RICINUS COMMUNIS L.) Y SUS MEZCLAS

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ABSTRACT

In this study, biodiesel (methyl ester) was produced from Castor Oil (*Ricinus communis* L.) (CO) using sodium hydroxide (*NaOH*) and methanol (CH_3OH) by the two-step transesterification method. Nine different fuel blends (2, 5, 10, 20, 30, 40, 50, 60 and 75% by volume blending with diesel) were prepared. The density values of Castor Oil Biodiesel (COB) and its blends were measured at the temperature range from 0 to 93°C in steps of 5°C and the kinematic viscosity values of COB and its blends were measured at the temperature range from 30 to 100°C in the steps of 5°C. The results showed that the density, kinematic viscosity, calorific value, flash point, pH, copper strip corrosion and water content of COB are 932.40 $kg{\cdot}m^{-3}$, 15.069 $mm^2{\cdot}s^{-1}$, 38.600 $MJ{\cdot}kg^{-1}$, 182°C, 7, 1a and 1067.7 $mg{\cdot}kg^{-1}$, respectively. The density and kinematic viscosity of fuel samples decrease as temperature increases; and also these properties decrease as a result of the increase in the amount of diesel in the blends.

Keywords: *Castor oil, Transesterification, Fuel property, Biodiesel, Density, Kinematic viscosity.*

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RESUMEN

En este estudio, se produjo biodiesel (metil éter) a partir de aceite de ricino (*Ricinus communis* L.) (CO, de sus siglas en inglés) utilizando hidróxido de sodio ($NaOH$) y metanol (CH_3OH) a través del método de transesterificación en dos pasos. Se prepararon nueve mezclas diferentes (2, 5, 10, 20, 30, 40, 50, 60 y 75% dependiendo del volumen de la mezcla con biodiesel. Se estimaron los valores de densidad del biodiesel de aceite de ricino (COB, de sus siglas en ingles) y sus mezclas en un rango de temperatura de 0 a 93°C en intervalos de 5°C y también se estimaron los valores de viscosidad cinemática de COB y sus mezclas dentro del rango temperatura comprendido entre 30 y 100°C en intervalos de 5°C. Los resultados mostraron que la densidad, la viscosidad cinemática, el valor calorífico, el punto de ignición, pH, la corrosión de la franja de cobre y el contenido de agua del COB son 932.40 $kg\cdot m^{-3}$, 15.069 $mm^2\cdot s^{-1}$, 38.600 $MJ\cdot kg^{-1}$, 182°C, 7, 1a y 1067.7 $mg\cdot kg^{-1}$, respectivamente. La densidad y la viscosidad cinemática de las muestras de combustible disminuyen a medida que aumenta la temperatura; y también estas propiedades disminuyen como resultado del aumento en la cantidad de biodiesel en las mezclas.

Palabras clave: *Aceite de Ricino, Transesterificación, Propiedades del Combustible, Biodiesel, Densidad, Viscosidad Cinemática.*

RESUMO

Neste estudo, o biodiesel (metil éter) foi produzido a partir do óleo de rícino (*Ricinus communis* L.) (CO, por suas siglas em inglês) usando hidróxido de sódio ($NaOH$) e metanol (CH_3OH) através de um método de transesterificação de dois passos. Foram preparadas até nove misturas de combustível diferentes (2, 5, 10, 20, 30, 40, 50, 60 e 75% por volume de mistura com o diesel). Os valores de densidade do biodiesel de óleo de rícino (COB, por suas siglas em inglês) e as suas misturas foram calculados dentro do rango de temperatura de 0 a 93°C no passo de 5°C e os valores de viscosidade cinemática do COB e das misturas foram calculadas no rango de temperatura de 30 a 100°C no passo de 5°C. Os resultados demonstraron que a densidade, viscosidade cinemática, valor calorífico, ponto de fusão, PH, corrosão da faixa de cobre e conteúdo de água do COB eram de 932.40 $kg\cdot m^{-3}$, 15.069 $mm^2\cdot s^{-1}$, 38.600 $MJ\cdot kg^{-1}$, 182°C, 7, 1a e 1067.7 $mg\cdot kg^{-1}$, respectivamente. Os valores de densidade e viscosidade cinemática das amostras de combustível diminuem na medida em que aumenta a temperatura; e também essas propriedades diminuem em decorrência do aumento na quantidade de diesel nas misturas.

Palavras-chave: *Óleo de rícino, Transesterificação, Propriedades do Combustível, Biodiesel, Densidade, Viscosidade cinemática.*

1. INTRODUCTION

Since the beginning of civilization, human beings are struggling for making progress in almost all domains of our life as a means to fulfill bare necessities like shelter, food, clothing and energy, etc. In addition to environmental and socio-economic concerns, the increasing gap between energy demand and supply coupled with the focus of limited fossil fuel resources and price inflation, have led researchers to develop biodiesel as an eco-friendly alternative to diesel fuel (Mumtaz *et al*., 2012). The requirements for diesel fuels include the ability to flow in the fuel feed system and to lubricate fuel injection pumps and fuel injectors. The viability to use vegetable oil as a diesel fuel was first demonstrated in 1895 by Rudolph Diesel, who operated a diesel engine with peanut oil. It was later verified that, in order to improve vegetable oils capacity to be used as a diesel fuel, it was necessary to remove glycerol from their molecules. Finally, biodiesel is obtained after the glycerol removal (Valente *et al*., 2010).

Biodiesel is defined as the mono-alkyl esters of vegetable oils or animal fats. Vegetable oils and fats as alternative engine fuels are all extremely viscous with viscosities ranging from 10 to 17 times greater than petroleum diesel fuel. Biodiesel is produced by transesterifying the parent oil or fat to achieve a viscosity close to that of diesel. The chemical conversion of the oil to its corresponding fatty ester (biodiesel) is called transesterification. The purpose of the transesterification process is to lower the viscosity of the oil (Demirbas, 2007).

There are more than 350 oil-bearing plants identified (with thousands of sub-species) that could be used to grow a new crop of fuel every year. The productivity of perennials is higher; they avoid erosion and can also be cultivated in mountain areas. Some species can be harvested more than once a year. The fuel potentialities of many vegetable oils were considered as early as 1939 (Salvi & Panwar, 2012; Jahirul *et al*., 2013). Table 1 shows main feedstocks of biodiesel production.

The production of biodiesel using non-edible crops, inappropriate for human consumption due to the presence of toxic compounds, has been researched over the last few years. Among the most studied crops are: jatropha (*Jatropha curcas*), karanja (*Pongamia pinnata*), castor (*Ricinus communis*), coriander (*Coriandrum sativum*), tobacco seed (*Nicotiana tabacum*), rubber (*Hevea brasiliensis*) and wild mustard (*Brassica juncea*) (Dias *et al.*, 2013).

CO (castor bean, castor, castor oil plant, ricin, higuerilla, mamona, mamoeira, palma christi) is a member of the tropical spurge family (Euphorbiaceae) and can nowadays be found naturalized and cultivated in all temperate countries of the world. Castor is originally a tree or shrub that can grow above 10 m high, reaching an age of about 4 years. At present, the cultivated varieties grow to a height of 60-120 cm in 1 year, and several meters in perennial cultivation. Castor grows in the humid tropics to the subtropical dry zones (optimal precipitation 750-1000 mm, temperature 15-38°C) and can be also cultivated in southern Europe (Scholz & Nogueira, 2008).

CO, extracted from the seeds of *Ricinus communis* L., is viscous, pale yellow, non-volatile and non-drying oil (Hincapié, Mondragón & López, 2011). CO presents between 80-90% of ricinoleic acid (12-hydroxy-9-*cis*-octadecenoic acid). Such unique composition brings a disadvantage for its use for biodiesel production, since its viscosity is about 7 times higher than the one of other vegetable oils. Because CO is highly hygroscopic, water content might also be higher than desirable. To overcome such issues, its use in mixture with diesel has proven effective, namely in a 10% blend, to comply with specifications in standards (Dias *et al*., 2013).

Conceição *et al*. (2007) have stated that the oil ratio of CO plant changes at 47-49% range and its biodiesel cost is lower, in comparison with other plants. They found COB's viscosity value as 13.75 $mm^2 \cdot s^{-1}$ (at 40°C), sulphur value as 0.0001%, density as 0.9279 $g \cdot cm^{-3}$ (at 15°C), ASTM colour as yellow, flash point as 120°C and copper strip corrosion value as 1.

In their study compiling the characteristics of CO, Scholz and Nogueira (2008) determined density as 950-974 $kg \cdot m^{-3}$ (at 15°C), flash point as 229-260°C, kinematic viscosity as 240-300 $mm^2 \cdot s^{-1}$ (at 40°C), net calorific value as 37.2-39.5 $MJ \cdot kg^{-1}$, water content as 0.15-0.30% and iodine number as 82-90 g·Iodine $100 \cdot g^{-1}$.

Table 1. Main feedstocks of biodiesel production (Demirbas, 2008a, Demirbas 2008b, Kafuku & Mbarawa, 2010; Karmakar *et al.*, 2010; Singh & Singh, 2010; Kibazohi & Sangwan, 2011; Lin *et al.*, 2011; Shahid & Jamal, 2011; Atabani *et al.*, 2012; Borugadda & Goud, 2012; Balaji & Cheralathan, 2013; Saxena, Jawale & Joshipura, 2013; Issariyakul & Dalai, 2014).

Edible oils	Non-edible oils	Animal fats	Other sources
Soybean (*Glycine max*)	Jatropha (Jatropha curcas)	Pork lard	Bacteria
Rapeseed (*Brassica napus*)	Mahua (*Madhuca indica*)	Beef tallow	Algae (Cyanobacteri)
Safflower (*Carthamus tinctorius*)	Pongamia (*Pongamia pinnata*)	Poultry fat	Microalgae (Chlorellavulgaris)
Rice bran oil (*Oryza sativum*)	Camelina (*Camelina sativa*)	Fish oil	Terpenes
Barley	Karanja or honge (*Pongamia pinnata*)	Chicken fat	
Sesame (*Sesamum indicum*)	Cumaru		
Groundnut	Cynara cardunculus		
Pumpkinseed (*Oleum semen cucurbitae*)	Abutilon muticum		
Wheat	Neem (*Azadirachta indica*)		
Corn	Jojoba (*Simmondsia chinensis*)		
Coconut	Passion seed (*Passiflora edulis*)		
Canola	Moringa (*Moringa oleifera*)		
Peanut	Tobacco seed (*Nicotiana tabacum*)		
Palm (*Elaeis guineensis*)	Rubber seed tree (*Hevea brasiliensis*)		
Sunflower (*Heliantus annuus*)	Tall (*Carnegiea gigantean*)		
Cottonseed (*Gossypium hirsutum*)	Castor oil (*Ricinus communis*)		
Poppyseed (*Opium poppy*)	Coriander (*Coriandrum sativum*)		
Hazelnut	Coffee ground (*Coffea arabica*)		
Walnut	Wild mustard (*Brassica juncea*)		
Almond	Nagchampa (*Calophyllum inophyllum*)		
	Croton megalocarpus		
	Pachira glabra		
	Aleurites moluccana		
	Terminalia belerica		

Albuquerque *et al*. (2009) have produced biodiesel from castor, soybean, canola and cotton oil, and studied the fuel characteristics. They reported COB's specific weight as 920, kinematic viscosity as 13.5 cSt (at 40°C), iodine index as 85.2, acid value as 0.42 mg KOH·g^{-1}, free glycerol as 0.015 %m·m^{-1} and combined glycerol as 0.018 %m·m^{-1}.

Berman, Nizri and Wiesman (2011) produced biodiesel from CO, by using methanol and potassium hydroxide (KOH) through a single-stage transesterification process. They concluded COB's cetane number (48.9), cloud point (-14°C), oxidation stability (44 h at 110°C) values met ASTM D6751 standards, while kinematic viscosity (at 40°C) and distillation temperature (15.17 mm^2·s^{-1} and 398.7°C respectively) values did not meet the standards.

Valente *et al*., (2011) have produced biodiesels from frying oil and CO at 6:1 methanol to oil molar ratio, 0.5% of *NaOH* and 60°C reaction temperature, and they mixed these biodiesels with diesel fuel, at a ratio of 25, 50 and 75% to analyse density, kinematic viscosity, distillation temperature and sulphur contents. As a result, 35% COB concentration in diesel fuel met EN 14214 for biodiesel density, kinematic viscosity and distillation temperature at 90°C.

Knothe, Cermak and Evangelista (2012) showed that refined CO's kinematic viscosity (at 40°C), oxidative stability (at 110°C) and acid values were 256.69 mm^2·s^{-1}, 74.80 h and 0.323 mg KOH·g^{-1} respectively. Analysing the fuel characteristics of COB, cetane number as 37.55, kinematic viscosity as 14.82 mm^2·s^{-1} (at 40°C), oxidative stability as 5.87 h (at 110°C), yield point as -20°C, acid number as 0.148 mg KOH·g^{-1}, lubrication as 186 μm, density as 927.7 kg·m^{-3} (at 15°C), water content as 640 mg·kg^{-1}, phosphorous value as 0 mg·kg^{-1} and sulphur value as 0.2 mg·kg^{-1}.

In their studies analysing the physico-chemical characteristics of biodiesels produced from jatropha and CO, Okullo *et al*., (2012) indicated COB's kinematic viscosity as 17.10 mm^2·s^{-1} (at 40°C), flash point as 178°C, acid value as 2.11 mg KOH·g^{-1}, cloud point as -13°C, density as 910 kg·m^{-3} (at 15°C) and calorific value as 29.60 MJ·kg^{-1}. In their studies optimizing biodiesel production from CO, Dias *et al*. (2013) reached maximum productivity at 73.62% for 6:1 methanol to oil molar ratio, 1% of KOH, 65°C and 8 h reaction conditions. Following the optimization studies, they found the acid value was between 0.92-1.87 mg KOH·g^{-1}, kinematic viscosity value was between 18.3-60.9 mm^2·s^{-1} (at 40°C), flash point was between 165-186.5°C and copper strip corrosion value was class 1.

In this present work, biodiesel from CO was produced via the two-step transesterification method. Methanol was used as an alcohol and *NaOH* was used as a catalyst. Different kind of blends, such as B2, B5, B10, B20, B30, B40, B50, B60, B75 and pure COB, were prepared. Then, fuel properties of COB and its blends with diesel fuel were determined. Additionally, the density values of COB and its blends were measured at the temperature range from 0 to 93°C in the steps of 5°C and the kinematic viscosity values of COB and its blends were measured at the temperature range from 30 to 100°C in the steps of 5°C. This study is aimed to identify the effect of temperature and biodiesel concentration on the density and kinematic viscosity of biodiesel blends as well as to develop a correlation for biodiesel concentration, temperature, density and kinematic viscosity.

2. MATERIALS AND METHODS

Biodiesel Production

In this study, CO was purchased from a local oil plant. Ultraforce Euro Diesel was supplied from a petrol station for experiments. The experiment was performed in a laboratory scale apparatus. Biodiesel was produced from this vegetable oil by means of the two-step transesterification process. In this reaction, methanol and *NaOH* were used as an alcohol and a catalyst. The chemicals (methanol and *NaOH*), which were used during the experiments, were taken from Merck. The details of the transesterification process used in this experiment are shown in Figure 1.

For the first reaction, methanol (75% of oil) and *NaOH* (50% of oil), which is 150 mL of methanol and 1.75 g *NaOH*, were resolved in a magnetic mixer, obtaining methoxide. This mixture of methoxide was added to the 1000 mL CO mixed at 55°C, which is the best reaction temperature (the best esters yield). For the mixing, the circulation rate was set to 1000 min^{-1} and

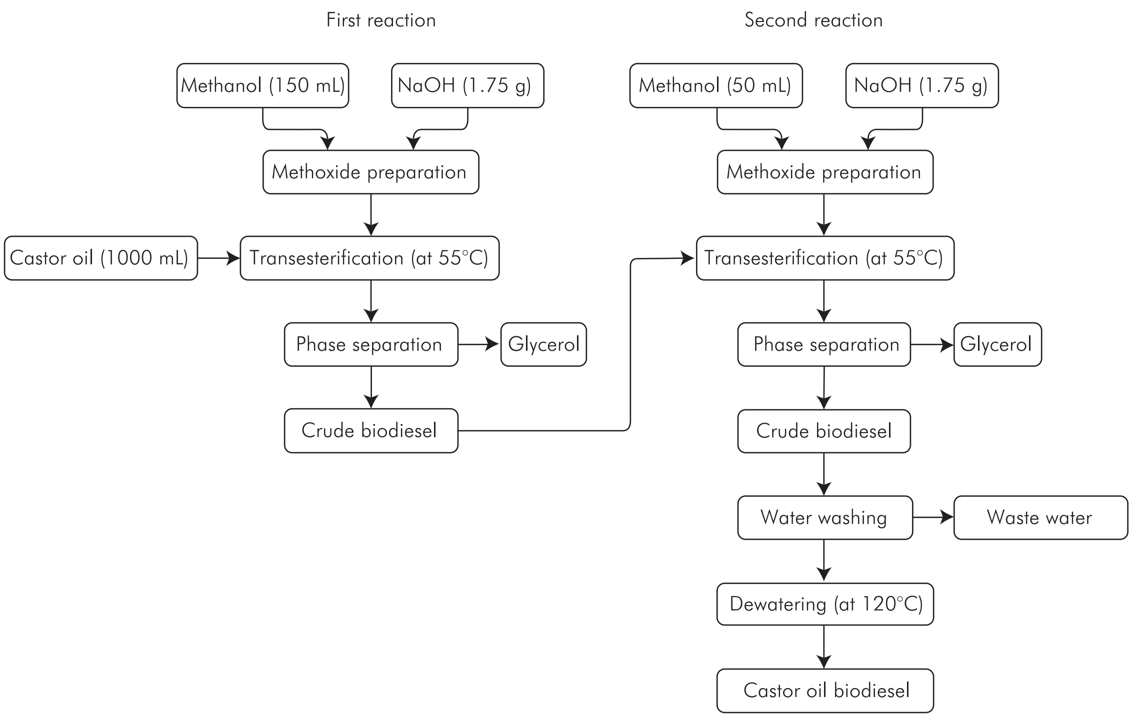

Figure 1. Flow diagram of biodiesel production process.

the mixture was mixed for 90 min. Later on, the mixer and heater were switched off. After waiting for 2 h for glycerol to subside, glycerol was removed (Figure 2). Later on, we proceeded to the second stage.

For the second reaction, methanol (25% of oil) and *NaOH* (50% of oil), which is 50 mL of methanol and 1.75 g *NaOH*, were resolved in a magnetic mixer, obtaining methoxide. The crude biodiesel, whose first reaction was attained, was heated up to 55ºC again by starting mixing and was submitted to reaction for 60 min. Then, the mixer and the heater were turned off. The resulting mixture was left to rest and glycerol was removed. The temperature of the crude biodiesel was increased up to 75ºC and methanol was removed. After waiting for 15 hours for glycerol to subside, glycerol was taken. Meanwhile, the pH value of the biodiesel was measured and repeatedly washed with distilled water until neutralization. It was submitted to a wash-off using the douching method (Figure 3).

The aim of the wash-off is to remove alcohol which does not get involved in reaction, remaining fatty acids, Na^+, K^+ ions, catalyst substance and glycerol which could have remained during separation. While washing, the temperature of biodiesel and distilled water was 55ºC

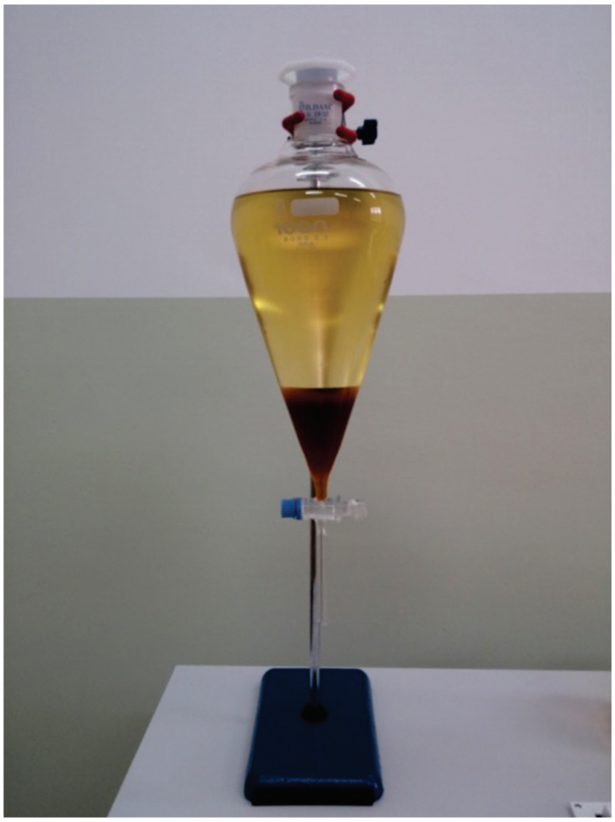

Figure 2. Glycerol formation after first reaction.

Figure 3. Biodiesel washing using distilled water.

and a total of 200 mL of distilled water was used in the process. After the washing process, it was rested for 12 h for water to subside. The subsided water was taken using a separating funnel. The washed biodiesel was taken to a magnetic mixer with heater again and was heated up to 120ºC which is where water goes beyond biodiesel. For biodiesel, drying was made at 120ºC for 2 h. Thus, biodiesel was produced from CO.

Preparing the Fuel Blends

Biodiesel can be used on its own, or by mixing it with diesel at any rate. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix (Aksoy, Baydir & Bayrakçeken, 2010a; Aksoy, Baydir & Bayrakçeken, 2010b). For example, fuel containing 20% biodiesel is labeled B20. Pure biodiesel is referred to as B100. However, two special blends are important. These are B2 and B20 fuels. B2 is preferred for improving lubrication, while B20 mixtures are preferred for better lubrication as well as decreased exhaust emissions. On the other hand, B100 provides both benefits, and can replace diesel, as long as it can be found cheap and at sufficient quantities (Sekmen, 2007; Eryilmaz, 2009). Blends of 20% biodiesel with 80% diesel can generally be used in diesel engines without modification. Also pure biodiesel (B100) can be used in diesel engines but may require certain modifications to avoid maintenance and performance problems. The common international standards for biodiesel are EN 14214 and ASTM D 6751 (Demirbas & Demirbas, 2010).

When blending diesel and COB, first 98, 95, 90, 80, 70, 60, 50, 40 and 25% diesel was put in a glass beaker, then 2, 5, 10, 20, 30, 40, 50, 60 and 75% biodiesel were added, respectively. The blend was tested to become homogenous first with laboratory type IKA brand Yellow line OST basic model mixer at 1500 min^{-1}, then with Yellow line brand DI 18 basic model homogenizer at 24000 min^{-1}, for 7.5 min each, for a total of 15 min. Following this, B2, B5, B10, B20, B30, B40, B50 and B75 mixtures were acquired.

Measurement Procedure of Fuel Properties

Important physical and chemical properties such as density, kinematic viscosity, flash point, water content, calorific value, pH and copper strip corrosion of diesel, CO, COB and COB-diesel blends were determined and presented in this study. Table 2 shows the apparatus used in this study to measure and to perform this analysis.

Fatty acid composition of CO and COB were analyzed by gas chromatography-mass spectrometry (GC-MS). GC-MS analysis was performed on an Agilent 6890N Network GC system combined with Agilent 5975C VL MSD Network Mass Selective Detector. The GC-MS conditions were; column, DB Waxetr, is 60.0 m x 0.25 mm x 0.25 μm; oven temperature programed as the column held initially at 60°C for 1 min after injection, then increased to 185°C with 1°C·min^{-1} heating ramp for 10 min and increased to 200°C with 5°C·min^{-1} heating ramp without hold; injector temperature is 250°C; carrier gas is *He*; inlet pressure is 25.36 psi; linear gas velocity is 7 cm·sec^{-1}; initial flow is 0.3 mL·min^{-1}; split ratio is 30.0:1 and injected volume is 1.0 μL.

3. RESULTS AND DISCUSSIONS

The fuel properties of diesel, CO, COB and its blends with diesel fuel are given in Table 3. When the fuel properties of alternative fuel -biodiesel of CO- obtained as a result of transesterification were analyzed

Table 2. The apparatus used to measure the fuel properties.

No	Property	Device	Range	Unit	Accuracy	Standard
1	Density/ specific gravity	Kem Kyoto brand DA-645 density/specific gravity meter	Density: 0.00-3000.00 Temperature: 0-93	$kg.m^{-3}$ °C	±0.05 ±0.03	EN ISO 3675 EN ISO 12185
2	Kinematic viscosity	Polyscience brand 7306A12E model viscometer	Ambient temperature-150 Measuring tube: 1.2-10 Measuring tube: 5-50 Timekeeper: 0-2400	°C $mm^2.s^{-1}$ $mm^2.s^{-1}$ s	±0.05 ±0.5 ±1 ±0.01	EN ISO 3104
3	Flash point	Rapid Tester brand RT-1 model flash point tester	-30-+300	°C	±1	EN ISO 2719 EN ISO 3679
4	Water content	Kem Kyoto Electronics brand MKC-520 model Karl-Fischer moisture titrator	10-300000	$mg.kg^{-1}$	±0.1	EN ISO 12937
5	Calorific value	IKA brand C200 model bomb calorimeter	0-40000	J	±0.1	DIN 51900-1,2,3
6	pH	Labkits brand ELE-PHP3BW model pH meter	pH range: 0-14 Temperature range: 0-100	pH °C	±0.01 ±1	-
7	Copper strip corrosion	Koehler brand K25330 model	Bath temperature range: Ambient temperature-190	°C	±1	EN ISO 2160

according to EN 14214 standard, and B2, B5, B10, B20, B30, B40, B50, B60, B75 fuel blends were analyzed according to EN 590, density, kinematic viscosity, calorific value, flash point, water content, copper strip corrosion analyses revealed values within limits up to B20 fuel blends. A cetane number is a characteristic of fuel that shows the ability of self-ignition in the cylinder of a diesel engine. The cetane number depends on fuel composition and influences the start of a diesel, the beginning of the combustion process, equal operation of a diesel, and the emission of exhaust gases. Cetane number (ignitability in diesel engines) of COB (80.2) is higher than standard diesel fuel (54) within in the standard values (Ozcanli *et al*., 2012). As well as COB-diesel fuel blends such as B2, B5, B10 and B20 can be used in diesel engine without any modification.

The composition and physico-chemical properties of oils have been found to vary depending on the plant location and the agricultural practices applied on the raw materials (Okullo *et al*., 2012). The composition of the raw material and biodiesel can be inferred by its fatty acid composition, analyzed by gas chromatography, as presented in Table 4. The obtained results match the composition expected according to the literature.

Temperature dependent density and kinematic viscosity of CO, rapeseed oil, soybean oil (Esteban *et al*., 2012) and diesel were shown in Figure 4. When compared, the density and kinematic viscosity of CO were higher than for the other vegetable oils. Densities of fatty acid methyl ester (FAME) with similar number of carbon atoms increase with an increased number of double bonds (for instance, $\rho_{C18:3} > \rho_{C18:2} > \rho_{C18:1} > \rho_{C18:0}$) (Ramírez-Verduzco, 2013). Knothe (2005) showed that the kinematic viscosity of biodiesel is influenced by structural arrangement of organic compounds present in the raw material. As can be seen in Table 4, CO and COB have approximately 90% ricinoleic acid, so the oil and biodiesel show more viscosity as compared to other oils and biodiesels.

With two step transesterification method, CO was transformed to biodiesel. Therefore, the density and kinematic viscosity of CO was decreased from 964.37

Table 3. Fuel properties of Diesel, CO, COB and its blends with diesel.

Fuel Properties	Density at 15°C, $kg \cdot m^{-3}$	Kinematic viscosity at 40°C, $mm^2 \cdot s^{-1}$	Flash point, °C	Water Content, $mg \cdot kg^{-1}$	Calorific value, $MJ \cdot kg^{-1}$	pH	Copper strip corrosion (3h at 50°C)
Fuels							
CO	964.37	241.465	205	1117.9	38.031	5.5	1a
B100	932.40	15.069	182	1067.7	38.600	7	1a
B75	902.11	10.113	81	908.88	40.538	6.5	1a
B60	883.32	7.580	71	843.54	41.725	6.5	1a
B50	873.97	6.449	69	712.04	42.157	6.5	1a
B40	862.12	5.413	66	695.68	43.712	6	1a
B30	851.71	4.528	64	421.63	44.366	6	1a
B20	839.62	3.772	62	219.32	45.177	5.5	1a
B10	828.88	3.213	61	188.09	46.480	5.5	1a
B5	823.45	2.960	60	95.067	47.025	5	1a
B2	822.43	2.937	59	61.928	47.101	5	1a
Diesel	820.23	2.627	58	22.916	47.445	5	1a

Table 4. Fatty acid composition (%) of CO and COB.

Fatty acids	CO (Measured)	CO (Cvengroš *et al.*, 2006)	CO (Okullo *et al.*, 2012)	CO (Kilic *et al.*, 2013)	COB (Measured)	COB (Zuleta *et al.*, 2012)	COB (Dias *et al.*, 2013)	COB (Kilic *et al.*, 2013)
C16:0	1.28	1.0	1.31	0.42	0.46	1.09	1.09	0.41
C18:0	0.99	0.7	1.22	0.33	0.28	0.87	0.94	0.13
C18:1	3.67	3.5	3.98	2.83	3.52	3.34	3.70	2.57
C18:2	4.48	4.4	4.66	4.03	4.69	4.87	4.44	5.00
C18:3	0.55	0.4	0.42	2.10	0.43	0.44	-	0.45
C18:1-OH	89.03	89	88.55	89.08	90.62	89.40	89.93	90.87
C20:0	-	-	-	-	-	-	-	0.34
C24:0	-	-	-	1.21	-	-	-	0.74

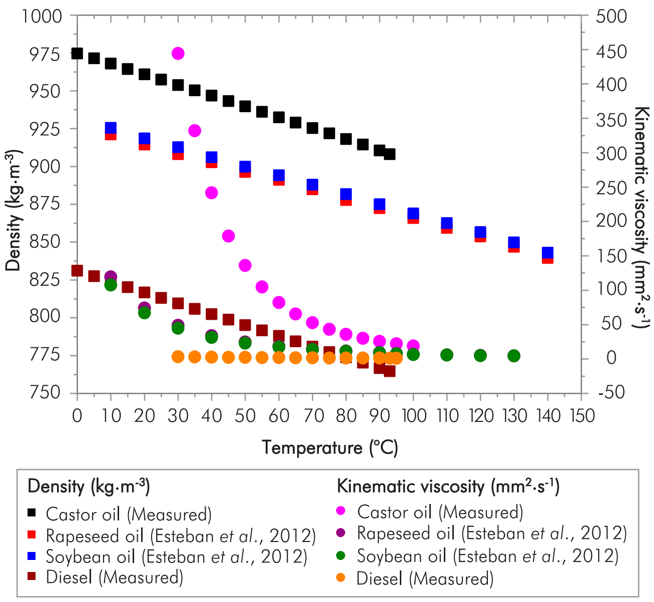

Figure 4. Temperature dependent density and kinematic viscosity of CO.

kg·m^{-3} to 928.67 kg·m^{-3} at 15°C and from 241.465 mm^2·s^{-1} to 15.069 mm^2·s^{-1} at 40°C, respectively. Prior literature reported the density and the kinematic viscosity of CO and COB as shown in Table 5. Empirical and literature results indicate that, COB does not meet the density and kinematic viscosity standards. Seed and oil productivity, oil acid composition and oil-fuel relations are characteristics affected by type and ambient conditions (Eryilmaz *et al.*, 2014a). With transesterification method, the density and kinematic viscosity values decreased about 4.35% and 94.02% (Asmare & Gabbiye, 2014), 3.07% and 94.26% (Conceição *et al.*, 2007), 2.63% and 90.00% (Sreenivas, Mamilla & Sekhar, 2011), 3.01% and 96.65% (Goswami, 2011), 0.52% and 92.76% (Shrirame, Panwar & Bamniya, 2011), 3.54% and 94.26% (Chakrabarti & Ali, 2009), 4.90% and 95.37% (Panwar *et al.*, 2010), respectively. We found out these ratios to be about 3.70% and 93.76%, respectively. The density and kinematic viscosity of COB exceeds the maximum specifications in standards, so that would only be possible to blend these esters with diesel fuel.

The density is specified in EN 14214 with a range of 860-900 kg·m^{-3} at 15°C and in EN 590 with a range of 820-845 kg·m^{-3} at 15°C. Figure 5 shows the density variations of diesel, COB, B2, B5, B10, B20, B30, B40, B50, B60, and B75 at a temperature range of 0 to 93°C. The densities of samples vary in the range of 822.43-902.11 kg·m^{-3} and higher than those of diesel fuel. As the density of COB is approximately 1.13 times higher

Table 5. Density and kinematic viscosity of COs and COBs.

Fuels	Density (kg·m^{-3})	Kinematic viscosity (mm^2·s^{-1})	References
CO	964.37	241.465	Measured
COB	928.67	15.069	Measured
CO	961.8	208.96	Asmare & Gabbiye, 2014
COB	920	12.5	Asmare & Gabbiye, 2014
COB	917[1]	14.4	Valente *et al.*, 2010
CO	957.3	239.39	Conceição *et al.*, 2007
COB	927.9	13.75	Conceição *et al.*, 2007
COB	922	20.02	Ramezani, Rowshanzamir & Eikani, 2010
COB	924.4	13.34	Cvengroš *et al.*, 2006
CO	950	240	Sreenivas *et al.*, 2011
COB	925	24	Sreenivas *et al.*, 2011
COB	920	11.5	Saribiyik *et al.*, 2010
CO	963	297[2]	Goswami, 2011
COB	934	9.4[2]	Goswami, 2011
COB	926.8	15.98	Ingle & Nandedkar, 2012
CO	940	222	Okullo *et al.*, 2012
CO	961	268	Shrirame *et al.*, 2011
COB	956	19.4	Shrirame *et al.*, 2011
COB	927.7	14.82	Knothe *et al.*, 2012
CO	958.4	239.39	Chakrabarti & Ali, 2009
COB	924.5	13.75	Chakrabarti & Ali, 2009
CO	960	226.82[2]	Panwar *et al.*, 2010
COB	913	10.5[2]	Panwar *et al.*, 2010

[1]at 20°C [2]at 38°C

than density of diesel fuel at 15°C, for the densities of B2, B5, B10, B20, B30, B40, B50, B60, and B75 are approximately 1.00, 1.00, 1.01, 1.02, 1.04, 1.05, 1.07, 1.08 and 1.10 times higher than density of diesel fuel in the same conditions, respectively. The maximum density values of each sample were measured at 0°C. In all cases, the density of biodiesels and its blends decreases as temperature increases; and also density decreases because of the increase in the amount of diesel in the blends. The blends with COB concentration up to 20% (for EN 590) could be acceptable.

Prediction of density and kinematic viscosity of biodiesel and the mixture of diesel fuel, which

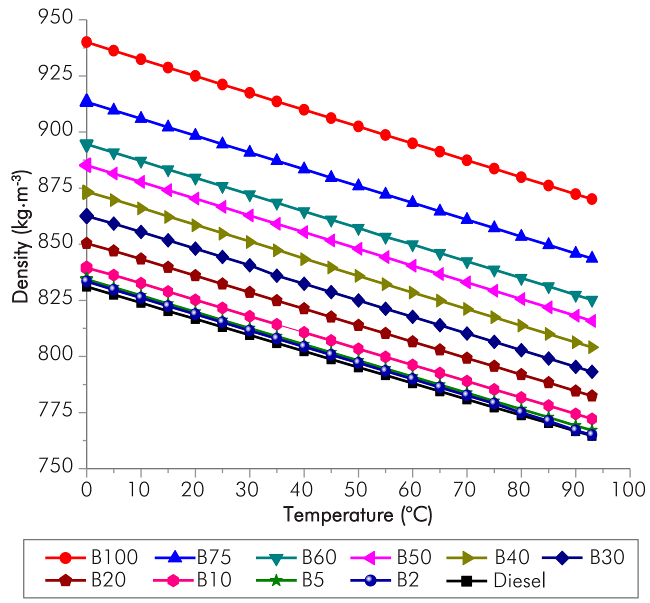

Figure 5. The variations of density of COB and its blends at different temperatures.

reduces time and workload at the same time, will allow preparation of the correct blending ratio for the diesel engines. A possible method for predicting the density of the biodiesel blends should be given by Ramírez-Verduzco *et al*. (2011), Rodenbush, Hsieh and Viswanath (1999), Esteban *et al*. (2012) at fixed concentration.

$$\rho = A + BT \tag{1}$$

Where T is the temperature in °C, A and B are the adjustable parameters. Empirical equations for density prediction (*Equation 1*) of diesel, biodiesel and its blends related to blending ratio at different temperatures are given in Table 6. In *Equation 1*, the coefficient of determination (R^2) is 0.9999 which indicates a very close match as compared to the measurements. Figure 6 shows those experimental and predicted density values of fuels. Error and percent relative error for density of biodiesel blends with these equations were shown in Figure 7.

For the remaining properties Kay's mixing rule is used:

$$\varphi_B = \sum_i^n x_i\,\varphi_i \tag{2}$$

Where φ_B is the property of the blend and φ_i is the respective property of the i^{th} component. Using volume

Table 6. First order polynomial equations (*Equation 1*) for the density of test fuels (0-93°C).

Fuel type	Empirical equations for density		R^2
CO	ρ=975.1025-0.7134T	(1)	0.9999
B100	ρ=939.9535-0.7514T	(2)	0.9999
B75	ρ=913.3464-0.7495T	(3)	0.9999
B60	ρ=894.5234-0.7459T	(4)	0.9999
B50	ρ=885.1661-0.7455T	(5)	0.9999
B40	ρ=873.1987-0.7445T	(6)	0.9999
B30	ρ=862.7499-0.7505T	(7)	0.9999
B20	ρ=850.5632-0.7335T	(8)	0.9999
B10	ρ=839.7204-0.7260T	(9)	0.9999
B5	ρ=834.3069-0.7233T	(10)	0.9999
B2	ρ=833.5038-0.7317T	(11)	0.9999
Diesel	ρ=830.9670-0.7148T	(11)	0.9999

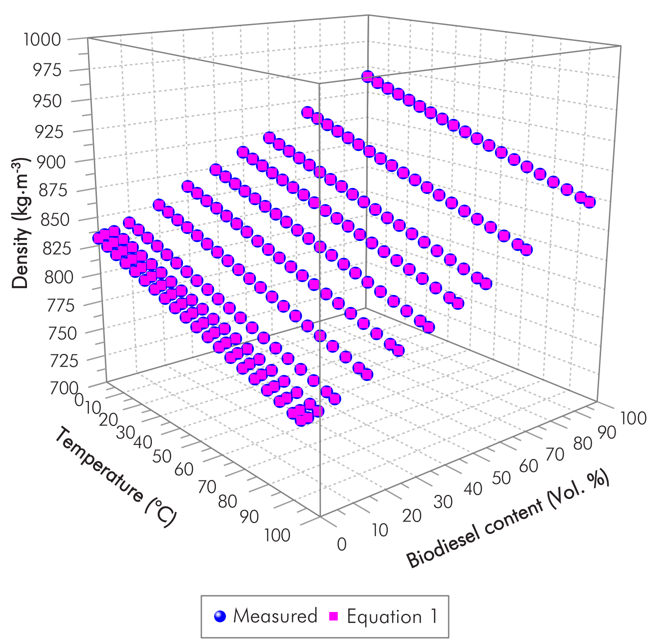

Figure 6. Experimental and predicted density values of fuels.

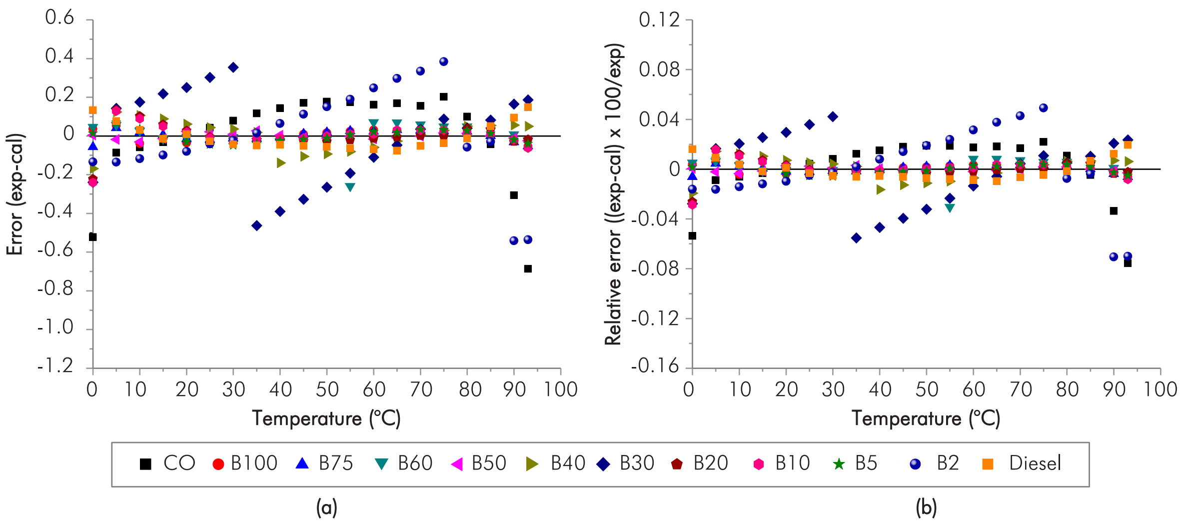

Figure 7. (a) Error and (b) percent relative error for density calculation with *Equation 1* of biodiesel blends.

fraction instead of molar fraction, *Equation 2* for a binary mixture takes the form of an arithmetic volume average:

$$\rho = V_1 \rho_1 + V_2 \rho_2 \qquad (3)$$

Where ρ is the density of the biodiesel blend, ρ_1 and ρ_2 are the density of the pure biodiesel and diesel in kg·m^{-3}, respectively. V_1 and V_2 are the volume percentage of the pure biodiesel and diesel, respectively (Benjumea, Agudelo & Agudelo, 2008; Al-Hamamre & Al-Salaymeh, 2014; Eryilmaz, 2012; Eryilmaz *et al.*, 2014b). Error and percent relative error of the fuel blends calculated from Kay's mixing rule is given in Figure 8. It is interesting to note that the lower blend ratio fuel exhibited greater average error of the experimental values. Therefore, with the increase in temperature, linearly decreasing characteristics of density became more dramatic for lower biodiesel blends and thus the model predictions has an slightly higher average error.

Figure 9 shows the kinematic viscosity variations of diesel, COB, B2, B5, B10, B20, B30, B40, B50, B60, and B75 at a temperature range of 30 to 100°C. The kinematic viscosities (at 40°C) of COB are 5.74 times that of diesel fuel, whereas the respective kinematic viscosity of COB was obtained to be 2.75 times that of diesel fuel by increasing temperature to 100°C.

To estimate the viscosity values of the mixtures, the equation suggested by Arrhenius and determined by

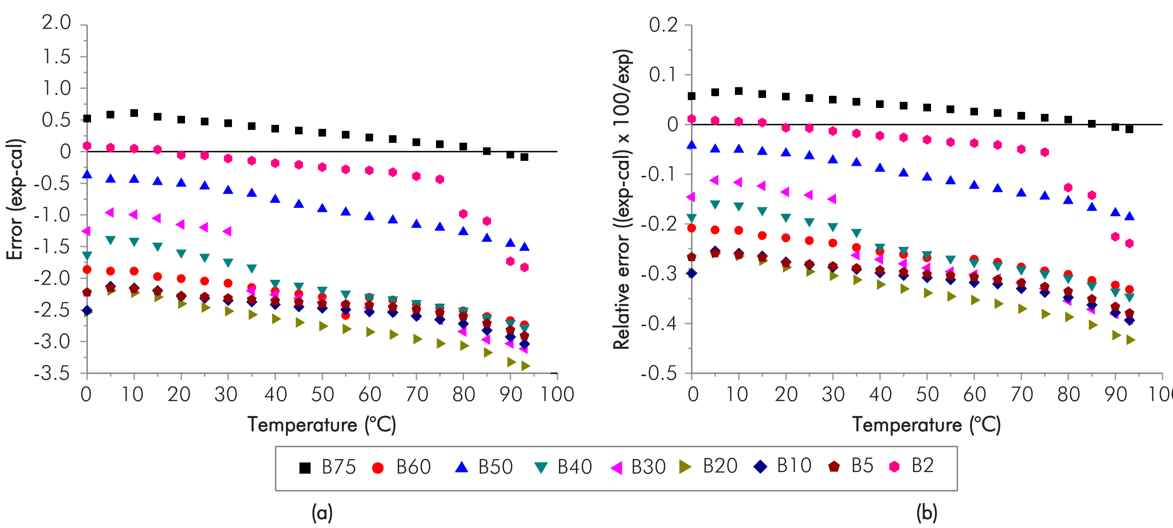

Figure 8. (a) Error and (b) percent relative error for density calculation with *Equation 3* of biodiesel blends.

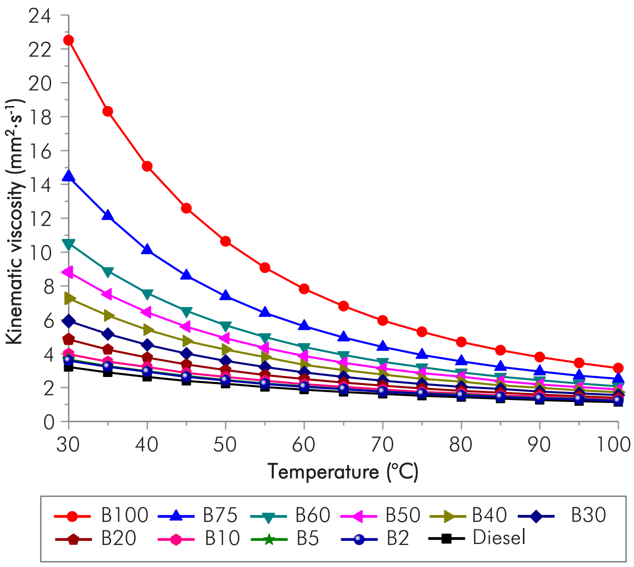

Figure 9. The variations of kinematic viscosity of COB and its blends with diesel fuel at different temperatures.

Grunberg and Nissan has been used (Eryilmaz, 2012).

$$ln(\eta_b) = ln(\eta_1)\, V_1 + ln(\eta_2)\, V_2 \qquad (4)$$

Where η_b represents the kinematic viscosity of blends at certain temperatures, η_1 and V_1 represents the kinematic viscosity of the first fuel used in the blend and the volumetric mixture rate, η_2 and V_2 the kinematic viscosity of the second fuel used in the blend and the volumetric mixture rate. A plot of $ln(\eta_b)$ versus x (blend ratio) (Figure 10) should give a straight line that can be analysed using linear regression to confirm the correlation from calculation of the slope is equal to $ln(\eta_{biodiesel}/\eta_{diesel})$ and intercept is equal to $ln(\eta_{diesel})$.

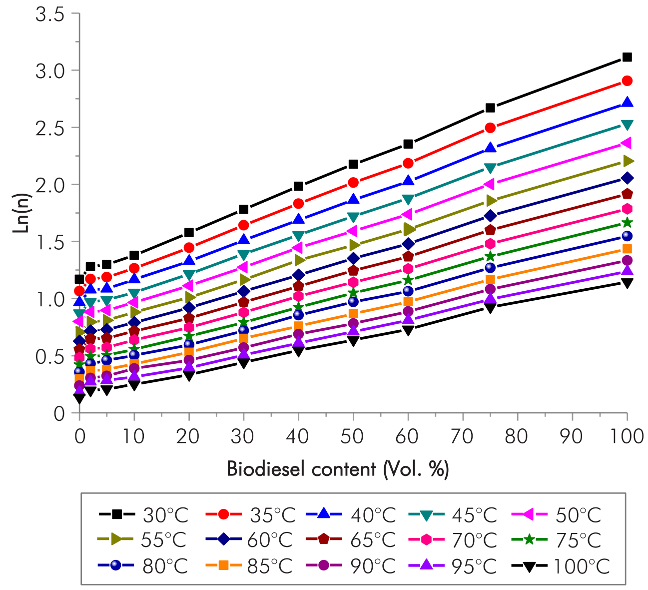

Figure 10. A plot of $ln(\eta)$ versus x (biodiesel content).

Table 7. Linear regression for kinematic viscosity prediction of biodiesel related to blending ratio.

T (°C)	$ln(\eta_{biodiesel}/\eta_{diesel})$	$ln(\eta_{diesel})$	Linear regressions	R^2
30	0.0194	1.169	ln η=0.0193x+1.201	(1) 0.9989
35	0.0184	1.065	ln η=0.0183x+1.094	(2) 0.9987
40	0.0175	0.966	ln η=0.0173x+0.997	(3) 0.9986
45	0.0166	0.873	ln η=0.0164x+0.899	(4) 0.9989
50	0.0156	0.801	ln η=0.0155x+0.817	(5) 0.9989
55	0.0150	0.706	ln η=0.0148x+0.731	(6) 0.9987
60	0.0143	0.628	ln η=0.0141x+0.650	(7) 0.9985
65	0.0136	0.555	ln η=0.0134x+0.578	(8) 0.9981
70	0.0130	0.484	ln η=0.0128x+0.504	(9) 0.9987
75	0.0125	0.419	ln η=0.0123x+0.435	(10) 0.9986
80	0.0119	0.356	ln η=0.0117x+0.381	(11) 0.9979
85	0.0114	0.296	ln η=0.0112x+0.316	(12) 0.9985
90	0.0110	0.237	ln η=0.0107x+0.260	(13) 0.9975
95	0.0106	0.181	ln η=0.0102x+0.210	(14) 0.9957
100	0.0101	0.135	ln η=0.0100x+0.149	(15) 0.9974

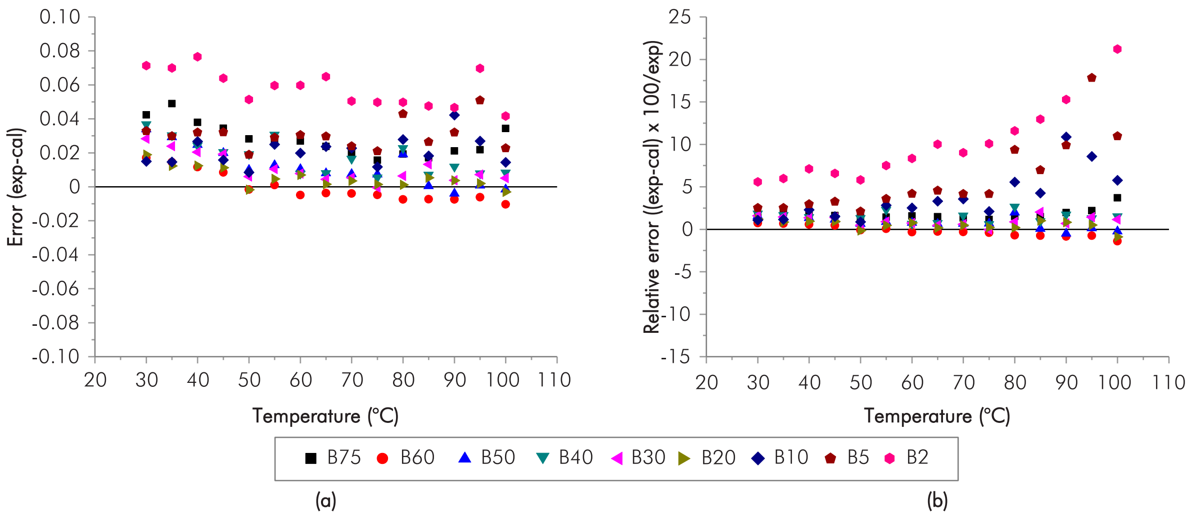

Figure 11. (a) Error and (b) percent relative error for kinematic viscosity calculation with linear regression of biodiesel blends.

Table 7 shows the linear fitting of biodiesel kinematic viscosity values versus blend ratio. R^2 values ranges from 0.9957 to 0.9989 and these formulas can be used to predict kinematic viscosities of COB and its blends with diesel fuel. Besides, for confirmation of this correlation, we calculated $ln(\eta_{biodiesel}/\eta_{diesel})$ and $ln(\eta_{diesel})$. After comparing the intercepts and slopes of those linear regression and $ln(\eta_{biodiesel}/\eta_{diesel})$ and $ln(\eta_{diesel})$, both of them proved to match each other.

Error and percent relative error of the fuel blends calculated from *Equation 4* is shown in Figure 11. The errors are ranged between -0.01-0.08 and the percent relative errors are ranged between 0-20.

Kinematic viscosity depending on the temperature change can be found using Andrade equation (Esteban *et al*., 2012; Ramírez-Verduzco *et al*., 2011; Rodenbush *et al*., 1999; Eryilmaz, 2012; Kimilu, Nyang'aya & Onyari, 2011; Tat & Van Gerpen, 1999; Yuan *et al*., 2005; Yuan, Hansen & Zhang, 2009; Kerschbaum & Rinke, 2004; Aksoy *et al*., 2014). 2 and 3 constant Andrade equations are;

$$ln(\eta) = A + \left(\frac{B}{T}\right) \tag{5}$$

$$ln(\eta) = A + \left(\frac{B}{T}\right) + \left(\frac{C}{T^2}\right) \tag{6}$$

where A, B and C are constant coefficients for the fluid, η is kinematic viscosity and T refers to the temperature.

Aksoy, Yabanova & Bayrakçeken (2011) and Aksoy *et al*., (2014) suggested equations for estimating the viscosity for biodiesels. These equations are:

$$ln(\eta)= A + Bln(T) \tag{7}$$

In these equations T is temperature and A, B and C are constants.

The correlation coefficients of the *Equations 5, 6* and 7 for each fuel sample were given in Table 8, and error and percent relative error were shown in Figure 12. As can be seen in Figure 12, *Equation 6* yields excellent results and minimum errors; however *Equation 7* shows the lowest agreement with experimental values. Figure 13 shows the experimental and predicted kinematic viscosity values of fuel. The whole set of experimental results, including those for density and kinematic viscosity are shown in Annex A and Annex B.

4. CONCLUSION

CO can be used as a biodiesel feedstock with its high oil content (40-55%) and its non-edible characteristics. In the present work, methyl ester was derived from CO and density, kinematic viscosity, water content, flash point, pH and copper strip corrosion properties of CO, COB and its blends with diesel fuel have been outlined. Fuel blends with up to 20% COB concentration in diesel fuel will meet present specifications for biodiesel density, kinematic viscosity, water content, flash point

Table 8. Equations for prediction of kinematic viscosity.

	Equation 5			Equation 6				Equation 7		
	A	B	R^2	A	B	C	R^2	A	B	R^2
CO	-12.495	5634.972	0.9990	-0.111	-2257.685	1.256E+06	0.9997	107.352	-17.722	0.9978
B100	-8.1100	3395.1267	0.9971	3.2846	-4022.3735	1.204E+06	0.9999	62.735	-10.440	0.9940
B75	-7.3101	3019.0104	0.9968	2.8684	-3631.0209	1.083E+06	0.9999	55.473	-9.246	0.9934
B60	-6.7753	2760.0307	0.9969	2.2430	-3147.4237	0.964E+06	0.9999	50.483	-8.429	0.9934
B50	-6.4274	2600.4618	0.9968	2.0320	-2949.9289	0.907E+06	0.9999	47.439	-7.928	0.9933
B40	-6.0256	2420.3550	0.9968	1.6868	-2648.9794	0.830E+06	0.9998	44.029	-7.365	0.9932
B30	-5.6695	2251.4983	0.9968	1.5280	-2487.2189	0.777E+06	0.9999	40.823	-6.839	0.9931
B20	-5.2743	2069.9812	0.9972	0.8652	-1979.5124	0.665E+06	0.9999	37.402	-6.276	0.9936
B10	-4.7670	1857.7184	0.9977	-0.1048	-1223.6842	0.507E+06	0.9997	33.469	-5.621	0.9945
B5	-4.6395	1794.2894	0.9973	0.3418	-1500.1539	0.543E+06	0.9998	32.266	-5.425	0.9938
B2	-4.6369	1788.7082	0.9977	-0.1601	-1172.0837	0.488E+06	0.9998	32.157	-5.408	0.9945
Diesel	-4.4963	1712.5068	0.9981	-0.5600	-892.8429	0.430E+06	0.9999	30.709	-5.174	0.9951

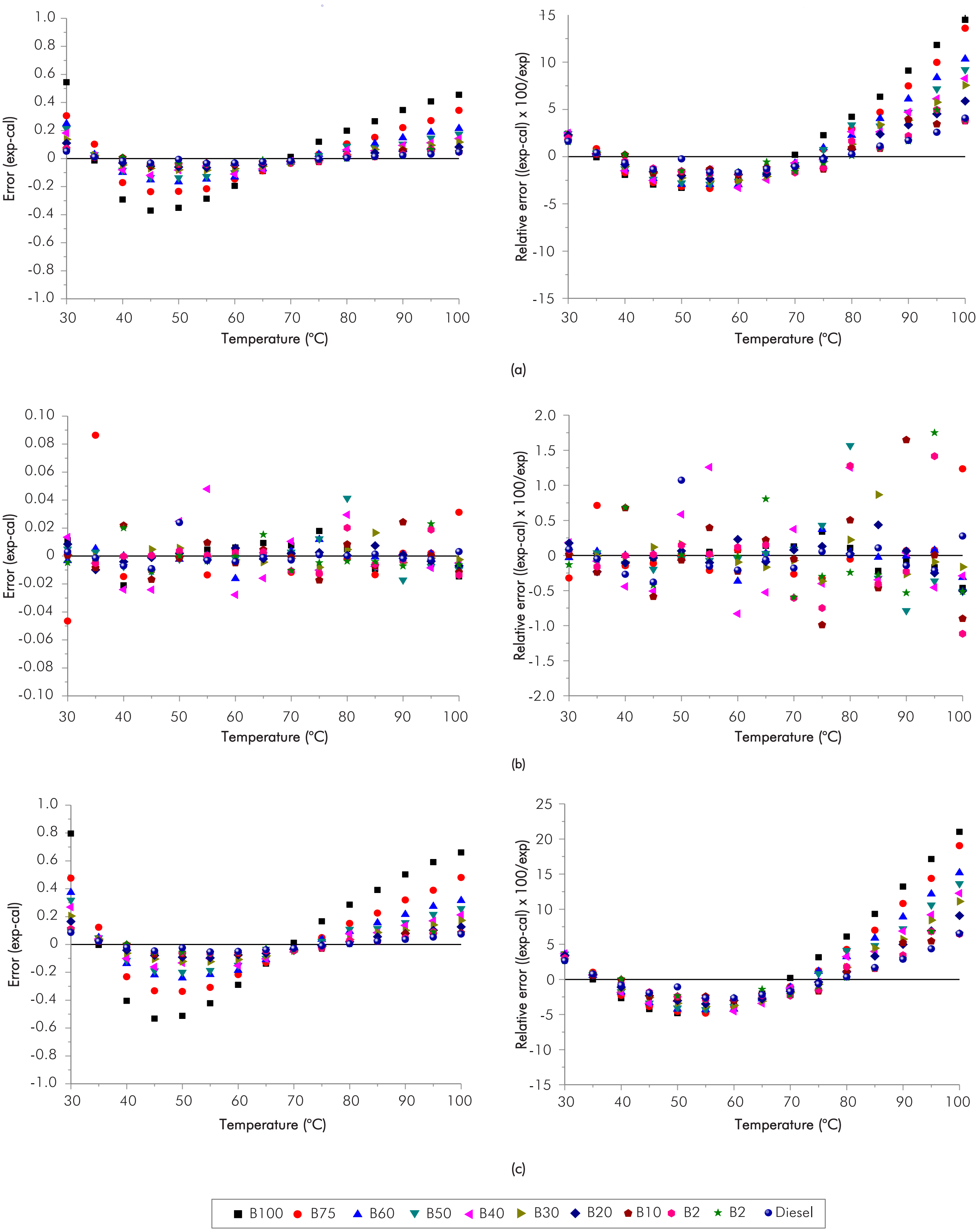

Figure 12. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5*, (b) *Equation 6*, (c) *Equation 7*.

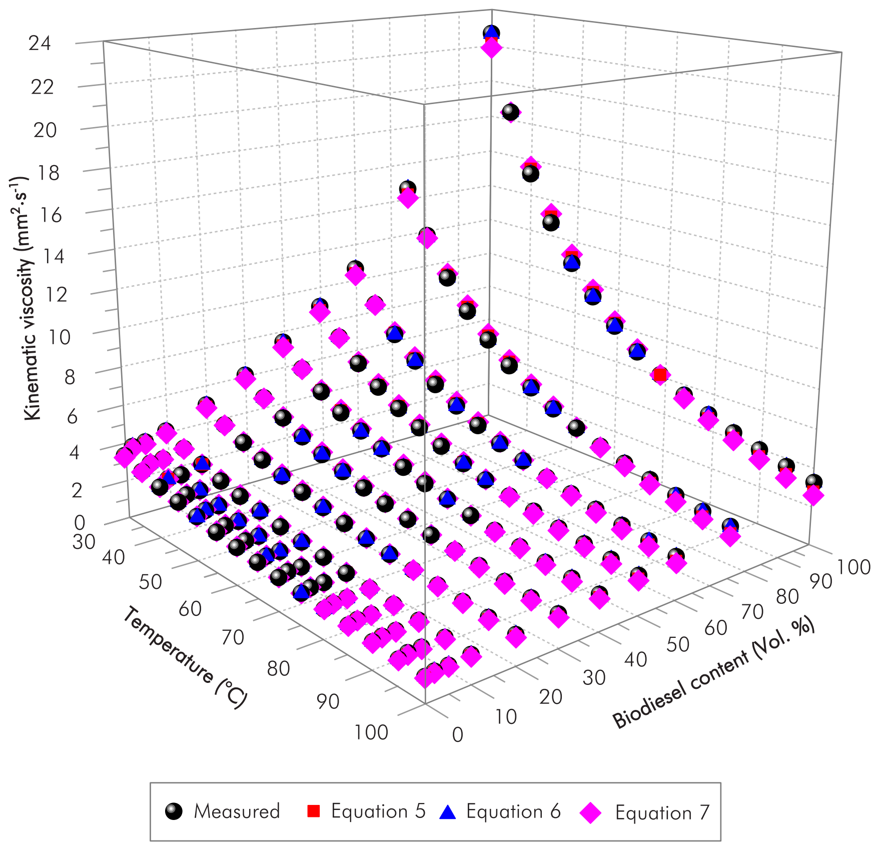

Figure 13. Experimental and predicted kinematic viscosity values of fuels.

and copper strip corrosion. It was not possible to obtain a product conforming EN 14214 and EN 590, as expected, mainly due to the high density and kinematic viscosity. The density and kinematic viscosity of COB and its blends with diesel fuel decrease as temperature increases; and also density and kinematic viscosity decrease because of the increase in the amount of diesel in the blends. The results obtained are valuable to continue studies regarding both the use CO in Turkey and the application of CO for biodiesel production.

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NOTATION

CO	Castor oil
COB	Castor oil biodiesel
FAME	Fatty acid methyl esters
NaOH	Sodium hydroxide
KOH	Potassium hydroxide
GC-MS	Gas chromatography-mass spectrometry
A, B, C	Adjustable parameters
ρ	Density, kg·m^{-3}
T	Temperature, °C
R^2	Coefficient of determination
φ_B	Property of the blend
φ_i	Respective property of the i^{th} component
V	Volume percentage
x_i	Molar fraction of the i^{th} component
x	Blend ratio
n	Number of component
η	Kinematic viscosity, mm^2·s^{-1}
η_b	Kinematic viscosity of the blend, mm^2·s^{-1}

ANNEX A

Table A1. Experimental and calculated densities, errors and relative errors using *Equation 1* of fuels at different temperatures.

Fuels	Castor oil				B100				B75			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	974.5800	975.1025	-0.5225	-0.0536	939.9900	939.9535	0.0365	0.0039	913.2900	913.3464	-0.0564	-0.0062
5	971.4500	971.5355	-0.0855	-0.0088	936.2500	936.1965	0.0535	0.0057	909.6400	909.5989	0.0411	0.0045
10	967.9100	967.9685	-0.0585	-0.0060	932.4000	932.4395	-0.0395	-0.0042	905.8700	905.8514	0.0186	0.0021
15	964.3700	964.4015	-0.0315	-0.0033	928.6700	928.6825	-0.0125	-0.0013	902.1100	902.1039	0.0061	0.0007
20	960.8400	960.8345	0.0055	0.0006	924.8900	924.9255	-0.0355	-0.0038	898.3400	898.3564	-0.0164	-0.0018
25	957.3100	957.2675	0.0425	0.0044	921.1300	921.1685	-0.0385	-0.0042	894.5900	894.6089	-0.0189	-0.0021
30	953.7800	953.7005	0.0795	0.0083	917.3800	917.4115	-0.0315	-0.0034	890.8500	890.8614	-0.0114	-0.0013
35	950.2500	950.1335	0.1165	0.0123	913.6300	913.6545	-0.0245	-0.0027	887.1000	887.1139	-0.0139	-0.0016
40	946.7100	946.5665	0.1435	0.0152	909.8900	909.8975	-0.0075	-0.0008	883.3600	883.3664	-0.0064	-0.0007
45	943.1700	942.9995	0.1705	0.0181	906.1500	906.1405	0.0095	0.0010	879.6300	879.6189	0.0111	0.0013
50	939.6100	939.4325	0.1775	0.0189	902.4000	902.3835	0.0165	0.0018	875.8900	875.8714	0.0186	0.0021
55	936.0400	935.8655	0.1745	0.0186	898.6500	898.6265	0.0235	0.0026	872.1500	872.1239	0.0261	0.0030
60	932.4600	932.2985	0.1615	0.0173	894.9000	894.8695	0.0305	0.0034	868.4000	868.3764	0.0236	0.0027
65	928.9000	928.7315	0.1685	0.0181	891.1400	891.1125	0.0275	0.0031	864.6600	864.6289	0.0311	0.0036
70	925.3200	925.1645	0.1555	0.0168	887.3900	887.3555	0.0345	0.0039	860.9100	860.8814	0.0286	0.0033
75	921.8000	921.5975	0.2025	0.0220	883.6200	883.5985	0.0215	0.0024	857.1600	857.1339	0.0261	0.0030
80	918.1300	918.0305	0.0995	0.0108	879.8500	879.8415	0.0085	0.0010	853.4100	853.3864	0.0236	0.0028
85	914.4200	914.4635	-0.0435	-0.0048	876.0900	876.0845	0.0055	0.0006	849.6400	849.6389	0.0011	0.0001
90	910.5900	910.8965	-0.3065	-0.0337	872.3000	872.3275	-0.0275	-0.0032	845.8600	845.8914	-0.0314	-0.0037
93	908.0700	908.7563	-0.6863	-0.0756	870.0200	870.0733	-0.0533	-0.0061	843.5900	843.6429	-0.0529	-0.0063

Table A1. Experimental and calculated densities, errors and relative errors using *Equation 1* of fuels at different temperatures. (Cont.)

Fuels	B60				B50				B40			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	894.5700	894.5234	0.0466	0.0052	885.1700	885.1661	0.0039	0.0004	873.0300	873.1987	-0.1687	-0.0193
5	890.8500	890.7939	0.0561	0.0063	881.4200	881.4386	-0.0186	-0.0021	869.6000	869.4762	0.1238	0.0142
10	887.0900	887.0644	0.0256	0.0029	877.6800	877.7111	-0.0311	-0.0035	865.8600	865.7537	0.1063	0.0123
15	883.3200	883.3349	-0.0149	-0.0017	873.9700	873.9836	-0.0136	-0.0016	862.1200	862.0312	0.0888	0.0103
20	879.6000	879.6054	-0.0054	-0.0006	870.2800	870.2561	0.0239	0.0027	858.3700	858.3087	0.0613	0.0071
25	875.8600	875.8759	-0.0159	-0.0018	866.5500	866.5286	0.0214	0.0025	854.6300	854.5862	0.0438	0.0051
30	872.1400	872.1464	-0.0064	-0.0007	862.8100	862.8011	0.0089	0.0010	850.9000	850.8637	0.0363	0.0043
35	868.3900	868.4169	-0.0269	-0.0031	859.1000	859.0736	0.0264	0.0031	847.1600	847.1412	0.0188	0.0022
40	864.6600	864.6874	-0.0274	-0.0032	855.3500	855.3461	0.0039	0.0005	843.2800	843.4187	-0.1387	-0.0164
45	860.9400	860.9579	-0.0179	-0.0021	851.6100	851.6186	-0.0086	-0.0010	839.5900	839.6962	-0.1062	-0.0126
50	857.2100	857.2284	-0.0184	-0.0021	847.8800	847.8911	-0.0111	-0.0013	835.8800	835.9737	-0.0937	-0.0112
55	853.2400	853.4989	-0.2589	-0.0303	844.1600	844.1636	-0.0036	-0.0004	832.1700	832.2512	-0.0812	-0.0098
60	849.8400	849.7694	0.0706	0.0083	840.4200	840.4361	-0.0161	-0.0019	828.4700	828.5287	-0.0587	-0.0071
65	846.1100	846.0399	0.0701	0.0083	836.7000	836.7086	-0.0086	-0.0010	824.7800	824.8062	-0.0262	-0.0032
70	842.3700	842.3104	0.0596	0.0071	832.9800	832.9811	-0.0011	-0.0001	821.0900	821.0837	0.0063	0.0008
75	838.6300	838.5809	0.0491	0.0059	829.2700	829.2536	0.0164	0.0020	817.3900	817.3612	0.0288	0.0035
80	834.9000	834.8514	0.0486	0.0058	825.5400	825.5261	0.0139	0.0017	813.6900	813.6387	0.0513	0.0063
85	831.1500	831.1219	0.0281	0.0034	821.8000	821.7986	0.0014	0.0002	809.9700	809.9162	0.0538	0.0066
90	827.4000	827.3924	0.0076	0.0009	818.0600	818.0711	-0.0111	-0.0014	806.2500	806.1937	0.0563	0.0070
93	825.1300	825.1547	-0.0247	-0.0030	815.8100	815.8346	-0.0246	-0.0030	804.0100	803.9602	0.0498	0.0062

Table A1. Experimental and calculated densities, errors and relative errors using *Equation 1* of fuels at different temperatures. (Cont.)

Fuels	B30				B20				B10			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	862.5100	862.7499	-0.2399	-0.0278	850.3400	850.5632	-0.2232	-0.0262	839.4800	839.7204	-0.2404	-0.0286
5	859.1400	858.9974	0.1426	0.0166	847.0300	846.8957	0.1343	0.0159	836.2200	836.0904	0.1296	0.0155
10	855.4200	855.2449	0.1751	0.0205	843.3300	843.2282	0.1018	0.0121	832.5500	832.4604	0.0896	0.0108
15	851.7100	851.4924	0.2176	0.0255	839.6200	839.5607	0.0593	0.0071	828.8800	828.8304	0.0496	0.0060
20	847.9900	847.7399	0.2501	0.0295	835.9200	835.8932	0.0268	0.0032	825.2200	825.2004	0.0196	0.0024
25	844.2900	843.9874	0.3026	0.0358	832.2200	832.2257	-0.0057	-0.0007	821.5600	821.5704	-0.0104	-0.0013
30	840.5900	840.2349	0.3551	0.0422	828.5400	828.5582	-0.0182	-0.0022	817.9200	817.9404	-0.0204	-0.0025
35	836.0200	836.4824	-0.4624	-0.0553	824.8700	824.8907	-0.0207	-0.0025	814.3000	814.3104	-0.0104	-0.0013
40	832.3400	832.7299	-0.3899	-0.0468	821.2000	821.2232	-0.0232	-0.0028	810.6700	810.6804	-0.0104	-0.0013
45	828.6500	828.9774	-0.3274	-0.0395	817.5300	817.5557	-0.0257	-0.0031	807.0400	807.0504	-0.0104	-0.0013
50	824.9600	825.2249	-0.2649	-0.0321	813.8600	813.8882	-0.0282	-0.0035	803.4200	803.4204	-0.0004	0.0000
55	821.2800	821.4724	-0.1924	-0.0234	810.2000	810.2207	-0.0207	-0.0026	799.8000	799.7904	0.0096	0.0012
60	817.6100	817.7199	-0.1099	-0.0134	806.5400	806.5532	-0.0132	-0.0016	796.1700	796.1604	0.0096	0.0012
65	813.9200	813.9674	-0.0474	-0.0058	802.8800	802.8857	-0.0057	-0.0007	792.5600	792.5304	0.0296	0.0037
70	810.2500	810.2149	0.0351	0.0043	799.2200	799.2182	0.0018	0.0002	788.9300	788.9004	0.0296	0.0038
75	806.5500	806.4624	0.0876	0.0109	795.5500	795.5507	-0.0007	-0.0001	785.3000	785.2704	0.0296	0.0038
80	802.7500	802.7099	0.0401	0.0050	791.9200	791.8832	0.0368	0.0046	781.6600	781.6404	0.0196	0.0025
85	799.0400	798.9574	0.0826	0.0103	788.2500	788.2157	0.0343	0.0044	778.0200	778.0104	0.0096	0.0012
90	795.3700	795.2049	0.1651	0.0208	784.5200	784.5482	-0.0282	-0.0036	774.3600	774.3804	-0.0204	-0.0026
93	793.1400	792.9534	0.1866	0.0235	782.3300	782.3477	-0.0177	-0.0023	772.1400	772.2024	-0.0624	-0.0081

Table A1. Experimental and calculated densities, errors and relative errors using *Equation 1* of fuels at different temperatures. (Cont.)

Fuels	B5				B2				Diesel			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	834.3200	834.3069	0.0131	0.0016	833.3700	833.5038	-0.1338	-0.0161	831.1000	830.9670	0.1330	0.0160
5	830.7600	830.6904	0.0696	0.0084	829.7100	829.8453	-0.1353	-0.0163	827.4700	827.3930	0.0770	0.0093
10	827.1100	827.0739	0.0361	0.0044	826.0700	826.1868	-0.1168	-0.0141	823.8500	823.8190	0.0310	0.0038
15	823.4500	823.4574	-0.0074	-0.0009	822.4300	822.5283	-0.0983	-0.0120	820.2300	820.2450	-0.0150	-0.0018
20	819.8100	819.8409	-0.0309	-0.0038	818.7900	818.8698	-0.0798	-0.0097	816.6800	816.6710	0.0090	0.0011
25	816.1800	816.2244	-0.0444	-0.0054	815.1700	815.2113	-0.0413	-0.0051	813.0700	813.0970	-0.0270	-0.0033
30	812.5600	812.6079	-0.0479	-0.0059	811.5300	811.5528	-0.0228	-0.0028	809.4800	809.5230	-0.0430	-0.0053
35	808.9500	808.9914	-0.0414	-0.0051	807.9100	807.8943	0.0157	0.0019	805.9000	805.9490	-0.0490	-0.0061
40	805.3500	805.3749	-0.0249	-0.0031	804.3000	804.2358	0.0642	0.0080	802.3300	802.3750	-0.0450	-0.0056
45	801.7400	801.7584	-0.0184	-0.0023	800.6900	800.5773	0.1127	0.0141	798.7500	798.8010	-0.0510	-0.0064
50	798.1300	798.1419	-0.0119	-0.0015	797.0700	796.9188	0.1512	0.0190	795.1700	795.2270	-0.0570	-0.0072
55	794.5300	794.5254	0.0046	0.0006	793.4500	793.2603	0.1897	0.0239	791.5900	791.6530	-0.0630	-0.0080
60	790.9300	790.9089	0.0211	0.0027	789.8500	789.6018	0.2482	0.0314	788.0100	788.0790	-0.0690	-0.0088
65	787.3100	787.2924	0.0176	0.0022	786.2400	785.9433	0.2967	0.0377	784.4300	784.5050	-0.0750	-0.0096
70	783.7100	783.6759	0.0341	0.0044	782.6200	782.2848	0.3352	0.0428	780.8800	780.9310	-0.0510	-0.0065
75	780.0900	780.0594	0.0306	0.0039	779.0100	778.6263	0.3837	0.0493	777.3200	777.3570	-0.0370	-0.0048
80	776.4700	776.4429	0.0271	0.0035	774.9100	774.9678	-0.0578	-0.0075	773.7700	773.7830	-0.0130	-0.0017
85	772.8400	772.8264	0.0136	0.0018	771.2800	771.3093	-0.0293	-0.0038	770.2600	770.2090	0.0510	0.0066
90	769.1900	769.2099	-0.0199	-0.0026	767.1100	767.6508	-0.5408	-0.0705	766.7300	766.6350	0.0950	0.0124
93	767.0000	767.0400	-0.0400	-0.0052	764.9200	765.4557	-0.5357	-0.0700	764.6400	764.4906	0.1494	0.0195

Table A2. The measured and calculated density values using *Equation 3* and errors and relative errors.

Fuels	B100	Diesel	B75				B60				B50			
T (°C)	Experimental	Experimental	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	939.9900	831.1000	913.2900	912.7675	0.5225	0.0572	894.5700	896.4340	-1.8640	-0.2084	885.1700	885.5450	-0.3750	-0.0424
5	936.2500	827.4700	909.6400	909.0550	0.5850	0.0643	890.8500	892.7380	-1.8880	-0.2119	881.4200	881.8600	-0.4400	-0.0499
10	932.4000	823.8500	905.8700	905.2625	0.6075	0.0671	887.0900	888.9800	-1.8900	-0.2131	877.6800	878.1250	-0.4450	-0.0507
15	928.6700	820.2300	902.1100	901.5600	0.5500	0.0610	883.3200	885.2940	-1.9740	-0.2235	873.9700	874.4500	-0.4800	-0.0549
20	924.8900	816.6800	898.3400	897.8375	0.5025	0.0559	879.6000	881.6060	-2.0060	-0.2281	870.2800	870.7850	-0.5050	-0.0580
25	921.1300	813.0700	894.5900	894.1150	0.4750	0.0531	875.8600	877.9060	-2.0460	-0.2336	866.5500	867.1000	-0.5500	-0.0635
30	917.3800	809.4800	890.8500	890.4050	0.4450	0.0500	872.1400	874.2200	-2.0800	-0.2385	862.8100	863.4300	-0.6200	-0.0719
35	913.6300	805.9000	887.1000	886.6975	0.4025	0.0454	868.3900	870.5380	-2.1480	-0.2474	859.1000	859.7650	-0.6650	-0.0774
40	909.8900	802.3300	883.3600	883.0000	0.3600	0.0408	864.6600	866.8660	-2.2060	-0.2551	855.3500	856.1100	-0.7600	-0.0889
45	906.1500	798.7500	879.6300	879.3000	0.3300	0.0375	860.9400	863.1900	-2.2500	-0.2613	851.6100	852.4500	-0.8400	-0.0986
50	902.4000	795.1700	875.8900	875.5925	0.2975	0.0340	857.2100	859.5080	-2.2980	-0.2681	847.8800	848.7850	-0.9050	-0.1067
55	898.6500	791.5900	872.1500	871.8850	0.2650	0.0304	853.2400	855.8260	-2.5860	-0.3031	844.1600	845.1200	-0.9600	-0.1137
60	894.9000	788.0100	868.4000	868.1775	0.2225	0.0256	849.8400	852.1440	-2.3040	-0.2711	840.4200	841.4550	-1.0350	-0.1232
65	891.1400	784.4300	864.6600	864.4625	0.1975	0.0228	846.1100	848.4560	-2.3460	-0.2773	836.7000	837.7850	-1.0850	-0.1297
70	887.3900	780.8800	860.9100	860.7625	0.1475	0.0171	842.3700	844.7860	-2.4160	-0.2868	832.9800	834.1350	-1.1550	-0.1387
75	883.6200	777.3200	857.1600	857.0450	0.1150	0.0134	838.6300	841.1000	-2.4700	-0.2945	829.2700	830.4700	-1.2000	-0.1447
80	879.8500	773.7700	853.4100	853.3300	0.0800	0.0094	834.9000	837.4180	-2.5180	-0.3016	825.5400	826.8100	-1.2700	-0.1538
85	876.0900	770.2600	849.6400	849.6325	0.0075	0.0009	831.1500	833.7580	-2.6080	-0.3138	821.8000	823.1750	-1.3750	-0.1673
90	872.3000	766.7300	845.8600	845.9075	-0.0475	-0.0056	827.4000	830.0720	-2.6720	-0.3229	818.0600	819.5150	-1.4550	-0.1779
93	870.0200	764.6400	843.5900	843.6750	-0.0850	-0.0101	825.1300	827.8680	-2.7380	-0.3318	815.8100	817.3300	-1.5200	-0.1863

Table A2. The measured and calculated density values using *Equation 3* and errors and relative errors. (Cont.).

Fuels	B40				B30				B20			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	873.0300	874.6560	-1.6260	-0.1862	862.5100	863.7670	-1.2570	-0.1457	850.3400	852.8780	-2.5380	-0.2985
5	869.6000	870.9820	-1.3820	-0.1589	859.1400	860.1040	-0.9640	-0.1122	847.0300	849.2260	-2.1960	-0.2593
10	865.8600	867.2700	-1.4100	-0.1628	855.4200	856.4150	-0.9950	-0.1163	843.3300	845.5600	-2.2300	-0.2644
15	862.1200	863.6060	-1.4860	-0.1724	851.7100	852.7620	-1.0520	-0.1235	839.6200	841.9180	-2.2980	-0.2737
20	858.3700	859.9640	-1.5940	-0.1857	847.9900	849.1430	-1.1530	-0.1360	835.9200	838.3220	-2.4020	-0.2873
25	854.6300	856.2940	-1.6640	-0.1947	844.2900	845.4880	-1.1980	-0.1419	832.2200	834.6820	-2.4620	-0.2958
30	850.9000	852.6400	-1.7400	-0.2045	840.5900	841.8500	-1.2600	-0.1499	828.5400	831.0600	-2.5200	-0.3041
35	847.1600	848.9920	-1.8320	-0.2163	836.0200	838.2190	-2.1990	-0.2630	824.8700	827.4460	-2.5760	-0.3123
40	843.2800	845.3540	-2.0740	-0.2459	832.3400	834.5980	-2.2580	-0.2713	821.2000	823.8420	-2.6420	-0.3217
45	839.5900	841.7100	-2.1200	-0.2525	828.6500	830.9700	-2.3200	-0.2800	817.5300	820.2300	-2.7000	-0.3303
50	835.8800	838.0620	-2.1820	-0.2610	824.9600	827.3390	-2.3790	-0.2884	813.8600	816.6160	-2.7560	-0.3386
55	832.1700	834.4140	-2.2440	-0.2697	821.2800	823.7080	-2.4280	-0.2956	810.2000	813.0020	-2.8020	-0.3458
60	828.4700	830.7660	-2.2960	-0.2771	817.6100	820.0770	-2.4670	-0.3017	806.5400	809.3880	-2.8480	-0.3531
65	824.7800	827.1140	-2.3340	-0.2830	813.9200	816.4430	-2.5230	-0.3100	802.8800	805.7720	-2.8920	-0.3602
70	821.0900	823.4840	-2.3940	-0.2916	810.2500	812.8330	-2.5830	-0.3188	799.2200	802.1820	-2.9620	-0.3706
75	817.3900	819.8400	-2.4500	-0.2997	806.5500	809.2100	-2.6600	-0.3298	795.5500	798.5800	-3.0300	-0.3809
80	813.6900	816.2020	-2.5120	-0.3087	802.7500	805.5940	-2.8440	-0.3543	791.9200	794.9860	-3.0660	-0.3872
85	809.9700	812.5920	-2.6220	-0.3237	799.0400	802.0090	-2.9690	-0.3716	788.2500	791.4260	-3.1760	-0.4029
90	806.2500	808.9580	-2.7080	-0.3359	795.3700	798.4010	-3.0310	-0.3811	784.5200	787.8440	-3.3240	-0.4237
93	804.0100	806.7920	-2.7820	-0.3460	793.1400	796.2540	-3.1140	-0.3926	782.3300	785.7160	-3.3860	-0.4328

Table A2. The measured and calculated density values using *Equation 3* and errors and relative errors. (Cont.).

Fuels	B10				B5				B2			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
0	839.4800	841.9890	-2.5090	-0.2989	834.3200	836.5445	-2.2245	-0.2666	833.3700	833.2778	0.0922	0.0111
5	836.2200	838.3480	-2.1280	-0.2545	830.7600	832.9090	-2.1490	-0.2587	829.7100	829.6456	0.0644	0.0078
10	832.5500	834.7050	-2.1550	-0.2588	827.1100	829.2775	-2.1675	-0.2621	826.0700	826.0210	0.0490	0.0059
15	828.8800	831.0740	-2.1940	-0.2647	823.4500	825.6520	-2.2020	-0.2674	822.4300	822.3988	0.0312	0.0038
20	825.2200	827.5010	-2.2810	-0.2764	819.8100	822.0905	-2.2805	-0.2782	818.7900	818.8442	-0.0542	-0.0066
25	821.5600	823.8760	-2.3160	-0.2819	816.1800	818.4730	-2.2930	-0.2809	815.1700	815.2312	-0.0612	-0.0075
30	817.9200	820.2700	-2.3500	-0.2873	812.5600	814.8750	-2.3150	-0.2849	811.5300	811.6380	-0.1080	-0.0133
35	814.3000	816.6730	-2.3730	-0.2914	808.9500	811.2865	-2.3365	-0.2888	807.9100	808.0546	-0.1446	-0.0179
40	810.6700	813.0860	-2.4160	-0.2980	805.3500	807.7080	-2.3580	-0.2928	804.3000	804.4812	-0.1812	-0.0225
45	807.0400	809.4900	-2.4500	-0.3036	801.7400	804.1200	-2.3800	-0.2969	800.6900	800.8980	-0.2080	-0.0260
50	803.4200	805.8930	-2.4730	-0.3078	798.1300	800.5315	-2.4015	-0.3009	797.0700	797.3146	-0.2446	-0.0307
55	799.8000	802.2960	-2.4960	-0.3121	794.5300	796.9430	-2.4130	-0.3037	793.4500	793.7312	-0.2812	-0.0354
60	796.1700	798.6990	-2.5290	-0.3176	790.9300	793.3545	-2.4245	-0.3065	789.8500	790.1478	-0.2978	-0.0377
65	792.5600	795.1010	-2.5410	-0.3206	787.3100	789.7655	-2.4555	-0.3119	786.2400	786.5642	-0.3242	-0.0412
70	788.9300	791.5310	-2.6010	-0.3297	783.7100	786.2055	-2.4955	-0.3184	782.6200	783.0102	-0.3902	-0.0499
75	785.3000	787.9500	-2.6500	-0.3375	780.0900	782.6350	-2.5450	-0.3262	779.0100	779.4460	-0.4360	-0.0560
80	781.6600	784.3780	-2.7180	-0.3477	776.4700	779.0740	-2.6040	-0.3354	774.9100	775.8916	-0.9816	-0.1267
85	778.0200	780.8430	-2.8230	-0.3628	772.8400	775.5515	-2.7115	-0.3508	771.2800	772.3766	-1.0966	-0.1422
90	774.3600	777.2870	-2.9270	-0.3780	769.1900	772.0085	-2.8185	-0.3664	767.1100	768.8414	-1.7314	-0.2257
93	772.1400	775.1780	-3.0380	-0.3935	767.0000	769.9090	-2.9090	-0.3793	764.9200	766.7476	-1.8276	-0.2389

ANNEX B

Table B1. The measured kinematic viscosity values, the calculated kinematic values with *Equation 4*, errors and relative errors between the measured and calculated kinematic viscosity values.

Fuels	B100	Diesel	B75				B60				B50			
T (°C)	Experimental	Experimental	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	22.5100	3.2190	14.4410	13.8424	0.5986	4.1450	10.5180	10.3398	0.1782	1.6939	8.8060	8.5123	0.2937	3.3349
35	18.3020	2.9010	12.1280	11.5481	0.5799	4.7814	8.8880	8.7603	0.1277	1.4369	7.5030	7.2866	0.2164	2.8846
40	15.0690	2.6270	10.1130	9.7371	0.3759	3.7173	7.5800	7.4926	0.0874	1.1525	6.4490	6.2918	0.1572	2.4382
45	12.5830	2.3940	8.6020	8.3103	0.2917	3.3905	6.5340	6.4792	0.0548	0.8390	5.5990	5.4885	0.1105	1.9735
50	10.6320	2.2270	7.3980	7.1927	0.2053	2.7752	5.6800	5.6893	-0.0093	-0.1633	4.9150	4.8659	0.0491	0.9980
55	9.0720	2.0260	6.4030	6.2364	0.1666	2.6012	4.9860	4.9806	0.0054	0.1092	4.3420	4.2872	0.0548	1.2627
60	7.8180	1.8730	5.6190	5.4696	0.1494	2.6587	4.3930	4.4144	-0.0214	-0.4873	3.8670	3.8266	0.0404	1.0439
65	6.8020	1.7420	4.9550	4.8388	0.1162	2.3447	3.9300	3.9446	-0.0146	-0.3711	3.4700	3.4422	0.0278	0.7997
70	5.9650	1.6220	4.3930	4.3075	0.0855	1.9473	3.5290	3.5431	-0.0141	-0.4003	3.1340	3.1105	0.0235	0.7497
75	5.2850	1.5210	3.9320	3.8709	0.0611	1.5530	3.1960	3.2113	-0.0153	-0.4782	2.8560	2.8352	0.0208	0.7275
80	4.6970	1.4270	3.5550	3.4872	0.0678	1.9084	2.8950	2.9165	-0.0215	-0.7426	2.6390	2.5889	0.0501	1.8969
85	4.2000	1.3450	3.2140	3.1595	0.0545	1.6959	2.6440	2.6634	-0.0194	-0.7342	2.3780	2.3768	0.0012	0.0520
90	3.7980	1.2670	2.9480	2.8864	0.0616	2.0887	2.4300	2.4482	-0.0182	-0.7482	2.1850	2.1936	-0.0086	-0.3955
95	3.4480	1.1990	2.7060	2.6478	0.0582	2.1519	2.2460	2.2598	-0.0138	-0.6140	2.0350	2.0333	0.0017	0.0854
100	3.1420	1.1440	2.5260	2.4407	0.0853	3.3776	2.0760	2.0975	-0.0215	-1.0338	1.8930	1.8959	-0.0029	-0.1534

Table B1. The measured kinematic viscosity values, the calculated kinematic values with *Equation 4*, errors and relative errors between the measured and calculated kinematic viscosity values. (Cont.).

Fuels	B40				B30				B20			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	7.2700	7.0078	0.2622	3.6064	5.9350	5.7692	0.1658	2.7932	4.8400	4.7495	0.0905	1.8689
35	6.2470	6.0608	0.1862	2.9811	5.1630	5.0412	0.1218	2.3593	4.2450	4.1931	0.0519	1.2220
40	5.4130	5.2834	0.1296	2.3951	4.5280	4.4366	0.0914	2.0192	3.7720	3.7255	0.0465	1.2327
45	4.7450	4.6493	0.0957	2.0167	4.0150	3.9384	0.0766	1.9073	3.3740	3.3362	0.0378	1.1194
50	4.2420	4.1618	0.0802	1.8913	3.5810	3.5595	0.0215	0.6005	3.0390	3.0444	-0.0054	-0.1771
55	3.8050	3.6903	0.1147	3.0137	3.2100	3.1766	0.0334	1.0414	2.7470	2.7343	0.0127	0.4609
60	3.3430	3.3171	0.0259	0.7742	2.8980	2.8754	0.0226	0.7783	2.5100	2.4926	0.0174	0.6940
65	3.0280	3.0039	0.0241	0.7963	2.6330	2.6213	0.0117	0.4425	2.2910	2.2875	0.0035	0.1517
70	2.7760	2.7307	0.0453	1.6317	2.4100	2.3973	0.0127	0.5278	2.1120	2.1046	0.0074	0.3519
75	2.5170	2.5032	0.0138	0.5483	2.2090	2.2101	-0.0011	-0.0480	1.9540	1.9512	0.0028	0.1409
80	2.3510	2.2982	0.0528	2.2470	2.0530	2.0401	0.0129	0.6303	1.8130	1.8109	0.0021	0.1138
85	2.1360	2.1210	0.0150	0.7040	1.9180	1.8927	0.0253	1.3194	1.6980	1.6890	0.0090	0.5305
90	1.9890	1.9656	0.0234	1.1781	1.7680	1.7612	0.0068	0.3843	1.5840	1.5781	0.0059	0.3730
95	1.8440	1.8294	0.0146	0.7895	1.6580	1.6461	0.0119	0.7206	1.4840	1.4810	0.0030	0.1990
100	1.7280	1.7137	0.0143	0.8268	1.5570	1.5490	0.0080	0.5118	1.3960	1.4002	-0.0042	-0.2990

Table B1. The measured kinematic viscosity values, the calculated kinematic values with *Equation 4*, errors and relative errors between the measured and calculated kinematic viscosity values. (Cont.).

Fuels	B10				B5				B2			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	3.9690	3.9101	0.0589	1.4843	3.6660	3.5478	0.1182	3.2254	3.5940	3.3467	0.2473	6.8815
35	3.5390	3.4877	0.0513	1.4487	3.2770	3.1809	0.0961	2.9336	3.2280	3.0099	0.2181	6.7576
40	3.2130	3.1284	0.0846	2.6330	2.9600	2.8668	0.0932	3.1500	2.9370	2.7204	0.2166	7.3749
45	2.8710	2.8261	0.0449	1.5633	2.6860	2.6011	0.0849	3.1608	2.6380	2.4748	0.1632	6.1871
50	2.6260	2.6038	0.0222	0.8449	2.4540	2.4080	0.0460	1.8726	2.4190	2.2977	0.1213	5.0134
55	2.4130	2.3537	0.0593	2.4587	2.2480	2.1837	0.0643	2.8604	2.2160	2.0877	0.1283	5.7913
60	2.2040	2.1607	0.0433	1.9648	2.0740	2.0117	0.0623	3.0033	2.0460	1.9273	0.1187	5.8016
65	2.0440	1.9962	0.0478	2.3379	1.9210	1.8648	0.0562	2.9266	1.9100	1.7901	0.1199	6.2769
70	1.8900	1.8476	0.0424	2.2436	1.7730	1.7311	0.0419	2.3617	1.7510	1.6648	0.0862	4.9229
75	1.7430	1.7227	0.0203	1.1621	1.6530	1.6187	0.0343	2.0731	1.6390	1.5594	0.0796	4.8588
80	1.6530	1.6075	0.0455	2.7497	1.5810	1.5146	0.0664	4.2008	1.5360	1.4614	0.0746	4.8562
85	1.5350	1.5072	0.0278	1.8101	1.4620	1.4238	0.0382	2.6129	1.4430	1.3760	0.0670	4.6443
90	1.4750	1.4140	0.0610	4.1345	1.3820	1.3385	0.0435	3.1482	1.3570	1.2951	0.0619	4.5596
95	1.3690	1.3326	0.0364	2.6602	1.3300	1.2640	0.0660	4.9603	1.3130	1.2246	0.0884	6.7327
100	1.2840	1.2656	0.0184	1.4313	1.2310	1.2033	0.0277	2.2522	1.2170	1.1674	0.0496	4.0796

Table B2. The measured and calculated kinematic viscosities using linear regressions, errors and relative errors.

Fuels	B75				B60				B50			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	2.6701	2.6277	0.0423	1.5855	2.3531	2.3360	0.0171	0.7260	2.1754	2.1415	0.0339	1.5591
35	2.4955	2.4465	0.0490	1.9633	2.1847	2.1702	0.0145	0.6625	2.0153	1.9860	0.0293	1.4524
40	2.3138	2.2759	0.0379	1.6372	2.0255	2.0139	0.0116	0.5723	1.8639	1.8392	0.0247	1.3243
45	2.1520	2.1175	0.0345	1.6029	1.8770	1.8686	0.0084	0.4489	1.7226	1.7027	0.0199	1.1571
50	2.0012	1.9731	0.0281	1.4064	1.7370	1.7386	-0.0016	-0.0940	1.5923	1.5823	0.0100	0.6299
55	1.8568	1.8304	0.0264	1.4195	1.6066	1.6055	0.0011	0.0680	1.4683	1.4556	0.0127	0.8654
60	1.7262	1.6992	0.0269	1.5611	1.4800	1.4849	-0.0049	-0.3285	1.3525	1.3420	0.0105	0.7759
65	1.6004	1.5767	0.0237	1.4825	1.3686	1.3723	-0.0037	-0.2706	1.2442	1.2361	0.0080	0.6454
70	1.4800	1.4603	0.0197	1.3287	1.2610	1.2650	-0.0040	-0.3168	1.1423	1.1348	0.0075	0.6588
75	1.3691	1.3535	0.0157	1.1432	1.1619	1.1667	-0.0048	-0.4106	1.0494	1.0421	0.0073	0.6958
80	1.2684	1.2491	0.0193	1.5192	1.0630	1.0704	-0.0074	-0.6961	0.9704	0.9512	0.0192	1.9735
85	1.1675	1.1504	0.0171	1.4650	0.9723	0.9796	-0.0073	-0.7524	0.8663	0.8657	0.0005	0.0601
90	1.0811	1.0600	0.0211	1.9524	0.8879	0.8953	-0.0075	-0.8395	0.7816	0.7856	-0.0039	-0.5050
95	0.9955	0.9737	0.0218	2.1853	0.8092	0.8153	-0.0061	-0.7565	0.7105	0.7096	0.0009	0.1203
100	0.9266	0.8923	0.0344	3.7080	0.7304	0.7407	-0.0103	-1.4081	0.6382	0.6397	-0.0015	-0.2401

Table B2. The measured and calculated kinematic viscosities using linear regressions, errors and relative errors. (Cont.).

Fuels	B40				B30				B20			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	1.9838	1.9470	0.0367	1.8515	1.7809	1.7525	0.0283	1.5908	1.5769	1.5580	0.0189	1.1964
35	1.8321	1.8018	0.0303	1.6519	1.6415	1.6176	0.0239	1.4545	1.4457	1.4334	0.0123	0.8505
40	1.6888	1.6646	0.0242	1.4355	1.5103	1.4899	0.0204	1.3507	1.3276	1.3152	0.0124	0.9343
45	1.5571	1.5367	0.0204	1.3084	1.3900	1.3708	0.0193	1.3854	1.2161	1.2048	0.0113	0.9257
50	1.4450	1.4259	0.0191	1.3214	1.2756	1.2696	0.0060	0.4721	1.1115	1.1133	-0.0018	-0.1592
55	1.3363	1.3057	0.0306	2.2899	1.1663	1.1558	0.0105	0.8976	1.0105	1.0059	0.0046	0.4572
60	1.2069	1.1991	0.0078	0.6440	1.0640	1.0562	0.0078	0.7343	0.9203	0.9133	0.0070	0.7567
65	1.1079	1.0999	0.0080	0.7217	0.9681	0.9637	0.0044	0.4581	0.8290	0.8275	0.0015	0.1831
70	1.0210	1.0046	0.0165	1.6113	0.8796	0.8743	0.0053	0.6016	0.7476	0.7441	0.0035	0.4716
75	0.9231	0.9176	0.0055	0.5956	0.7925	0.7930	-0.0005	-0.0605	0.6699	0.6685	0.0014	0.2104
80	0.8548	0.8321	0.0227	2.6586	0.7193	0.7130	0.0063	0.8790	0.5950	0.5938	0.0011	0.1914
85	0.7589	0.7519	0.0071	0.9309	0.6513	0.6380	0.0133	2.0393	0.5295	0.5241	0.0053	1.0046
90	0.6876	0.6758	0.0119	1.7235	0.5698	0.5660	0.0039	0.6757	0.4600	0.4562	0.0037	0.8124
95	0.6119	0.6040	0.0079	1.2953	0.5056	0.4984	0.0072	1.4304	0.3947	0.3927	0.0020	0.5046
100	0.5470	0.5387	0.0083	1.5179	0.4428	0.4376	0.0051	1.1590	0.3336	0.3366	-0.0030	-0.8949

Table B2. The measured and calculated kinematic viscosities using linear regressions, errors and relative errors. (Cont.).

Fuels	B10				B5				B2			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	1.3785	1.3636	0.0150	1.0848	1.2991	1.2663	0.0328	2.5237	1.2793	1.2080	0.0713	5.5733
35	1.2638	1.2493	0.0146	1.1547	1.1869	1.1572	0.0298	2.5086	1.1719	1.1019	0.0700	5.9707
40	1.1672	1.1405	0.0267	2.2860	1.0852	1.0532	0.0320	2.9494	1.0774	1.0008	0.0766	7.1107
45	1.0547	1.0389	0.0158	1.4940	0.9881	0.9559	0.0321	3.2507	0.9700	0.9062	0.0639	6.5842
50	0.9655	0.9570	0.0085	0.8789	0.8977	0.8788	0.0189	2.1057	0.8834	0.8319	0.0514	5.8226
55	0.8809	0.8560	0.0249	2.8261	0.8100	0.7810	0.0290	3.5827	0.7957	0.7360	0.0597	7.4975
60	0.7903	0.7704	0.0198	2.5110	0.7295	0.6990	0.0305	4.1801	0.7159	0.6561	0.0598	8.3487
65	0.7149	0.6913	0.0237	3.3090	0.6528	0.6231	0.0297	4.5498	0.6471	0.5823	0.0648	10.0178
70	0.6366	0.6139	0.0227	3.5647	0.5727	0.5488	0.0239	4.1735	0.5602	0.5097	0.0505	9.0117
75	0.5556	0.5439	0.0117	2.1039	0.5026	0.4816	0.0209	4.1681	0.4941	0.4443	0.0498	10.0809
80	0.5026	0.4747	0.0279	5.5477	0.4581	0.4151	0.0429	9.3691	0.4292	0.3794	0.0498	11.5989
85	0.4285	0.4103	0.0183	4.2628	0.3798	0.3533	0.0265	6.9712	0.3667	0.3192	0.0476	12.9679
90	0.3887	0.3464	0.0422	10.8640	0.3235	0.2915	0.0320	9.8873	0.3053	0.2586	0.0467	15.2871
95	0.3141	0.2871	0.0270	8.5844	0.2852	0.2343	0.0509	17.8399	0.2723	0.2026	0.0697	25.5956
100	0.2500	0.2356	0.0144	5.7670	0.2078	0.1850	0.0228	10.9608	0.1964	0.1547	0.0417	21.2086

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.*

(a)

Fuels	Castor oil				B100				B75			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	444.0210	442.8213	1.1997	0.2702	22.5100	21.9660	0.5440	2.4168	14.4410	14.1357	0.3053	2.1144
35	331.8780	327.5232	4.3548	1.3122	18.3020	18.3160	-0.0140	-0.0763	12.1280	12.0265	0.1015	0.8371
40	241.4650	244.5899	-3.1249	-1.2941	15.0690	15.3613	-0.2923	-1.9401	10.1130	10.2849	-0.1719	-1.7002
45	178.8390	184.3404	-5.5014	-3.0762	12.5830	12.9548	-0.3718	-2.9547	8.6020	8.8389	-0.2369	-2.7545
50	135.9560	140.1533	-4.1973	-3.0872	10.6320	10.9830	-0.3510	-3.3014	7.3980	7.6319	-0.2339	-3.1623
55	104.7070	107.4516	-2.7446	-2.6212	9.0720	9.3583	-0.2863	-3.1560	6.4030	6.6193	-0.2163	-3.3784
60	81.9840	83.0398	-1.0558	-1.2878	7.8180	8.0124	-0.1944	-2.4860	5.6190	5.7656	-0.1466	-2.6096
65	65.3310	64.6650	0.6660	1.0194	6.8020	6.8916	-0.0896	-1.3167	4.9550	5.0426	-0.0876	-1.7679
70	52.7990	50.7245	2.0745	3.9290	5.9650	5.9536	0.0114	0.1905	4.3930	4.4275	-0.0345	-0.7850
75	43.1920	40.0678	3.1242	7.2333	5.2850	5.1650	0.1200	2.2703	3.9320	3.9020	0.0300	0.7639
80	35.8080	31.8620	3.9460	11.0199	4.6970	4.4989	0.1981	4.2172	3.5550	3.4511	0.1039	2.9215
85	30.1550	25.4994	4.6556	15.4390	4.2000	3.9339	0.2661	6.3366	3.2140	3.0629	0.1511	4.7017
90	25.5960	20.5329	5.0631	19.7809	3.7980	3.4525	0.3455	9.0965	2.9480	2.7273	0.2207	7.4878
95	21.9660	16.6313	5.3347	24.2862	3.4480	3.0408	0.4072	11.8090	2.7060	2.4361	0.2699	9.9749
100	19.0280	13.5474	5.4806	28.8030	3.1420	2.6874	0.4546	14.4699	2.5260	2.1826	0.3434	13.5954

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(a)

Fuels	B60				B50				B40			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	10.5180	810.2698	0.2482	2.3600	8.8060	8.5912	0.2148	2.4395	7.2700	7.0881	0.1819	2.5020
35	8.8880	8.8594	0.0286	0.3220	7.5030	7.4749	0.0281	0.3748	6.2470	6.2268	0.0202	0.3226
40	7.5800	7.6788	-0.0988	-1.3037	6.4490	6.5326	-0.0836	-1.2963	5.4130	5.4929	-0.0799	-1.4764
45	6.5340	6.6856	-0.1516	-2.3195	5.5990	5.7333	-0.1343	-2.3993	4.7450	4.8646	-0.1196	-2.5212
50	5.6800	5.8458	-0.1658	-2.9187	4.9150	5.0522	-0.1372	-2.7919	4.2420	4.3244	-0.0824	-1.9432
55	4.9860	5.1324	-0.1464	-2.9370	4.3420	4.4692	-0.1272	-2.9299	3.8050	3.8580	-0.0530	-1.3938
60	4.3930	4.5238	-0.1308	-2.9771	3.8670	3.9681	-0.1011	-2.6135	3.3430	3.4538	-0.1108	-3.3129
65	3.9300	4.0022	-0.0722	-1.8376	3.4700	3.5355	-0.0655	-1.8883	3.0280	3.1020	-0.0740	-2.4428
70	3.5290	3.5535	-0.0245	-0.6929	3.1340	3.1607	-0.0267	-0.8533	2.7760	2.7948	-0.0188	-0.6756
75	3.1960	3.1658	0.0302	0.9450	2.8560	2.8348	0.0212	0.7423	2.5170	2.5255	-0.0085	-0.3385
80	2.8950	2.8297	0.0653	2.2564	2.6390	2.5503	0.0887	3.3604	2.3510	2.2888	0.0622	2.6467
85	2.6440	2.5372	0.1068	4.0400	2.3780	2.3012	0.0768	3.2309	2.1360	2.0799	0.0561	2.6248
90	2.4300	2.2818	0.1482	6.1002	2.1850	2.0822	0.1028	4.7027	1.9890	1.8951	0.0939	4.7192
95	2.2460	2.0580	0.1880	8.3711	2.0350	1.8893	0.1457	7.1609	1.8440	1.7311	0.1129	6.1212
100	2.0760	1.8613	0.2147	10.3423	1.8930	1.7187	0.1743	9.2097	1.7280	1.5851	0.1429	8.2668

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(a)

Fuels	B30				B20				B10			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	5.9350	5.7980	0.1370	2.3086	4.8400	4.7301	0.1099	2.2712	3.9690	3.9003	0.0687	1.7312
35	5.1630	5.1397	0.0233	0.4507	4.2450	4.2340	0.0110	0.2592	3.5390	3.5311	0.0079	0.2224
40	4.5280	4.5738	-0.0458	-1.0110	3.7720	3.8034	-0.0314	-0.8320	3.2130	3.2071	0.0059	0.1844
45	4.0150	4.0851	-0.0701	-1.7459	3.3740	3.4281	-0.0541	-1.6034	2.8710	2.9216	-0.0506	-1.7620
50	3.5810	3.6614	-0.0804	-2.2454	3.0390	3.0998	-0.0608	-2.0005	2.6260	2.6692	-0.0432	-1.6453
55	3.2100	3.2926	-0.0826	-2.5741	2.7470	2.8115	-0.0645	-2.3496	2.4130	2.4453	-0.0323	-1.3405
60	2.8980	2.9704	-0.0724	-2.4998	2.5100	2.5576	-0.0476	-1.8956	2.2040	2.2462	-0.0422	-1.9129
65	2.6330	2.6880	-0.0550	-2.0874	2.2910	2.3331	-0.0421	-1.8366	2.0440	2.0684	-0.0244	-1.1932
70	2.4100	2.4394	-0.0294	-1.2213	2.1120	2.1340	-0.0220	-1.0411	1.8900	1.9093	-0.0193	-1.0196
75	2.2090	2.2201	-0.0111	-0.5008	1.9540	1.9569	-0.0029	-0.1482	1.7430	1.7664	-0.0234	-1.3453
80	2.0530	2.0258	0.0272	1.3241	1.8130	1.7989	0.0141	0.7774	1.6530	1.6379	0.0151	0.9127
85	1.9180	1.8533	0.0647	3.3733	1.6980	1.6576	0.0404	2.3814	1.5350	1.5219	0.0131	0.8510
90	1.7680	1.6996	0.0684	3.8669	1.5840	1.5308	0.0532	3.3604	1.4750	1.4170	0.0580	3.9297
95	1.6580	1.5624	0.0956	5.7673	1.4840	1.4167	0.0673	4.5325	1.3690	1.3219	0.0471	3.4384
100	1.5570	1.4395	0.1175	7.5497	1.3960	1.3139	0.0821	5.8795	1.2840	1.2355	0.0485	3.7772

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(a)

Fuels	B5				B2				Diesel			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	3.6660	3.5942	0.0718	1.9590	3.5940	3.5378	0.0562	1.5636	3.2190	3.1669	0.0521	1.6197
35	3.2770	3.2651	0.0119	0.3643	3.2280	3.2148	0.0132	0.4087	2.9010	2.8895	0.0115	0.3967
40	2.9600	2.9752	-0.0152	-0.5132	2.9370	2.9302	0.0068	0.2301	2.6270	2.6441	-0.0171	-0.6526
45	2.6860	2.7190	-0.0330	-1.2281	2.6380	2.6787	-0.0407	-1.5413	2.3940	2.4264	-0.0324	-1.3528
50	2.4540	2.4918	-0.0378	-1.5395	2.4190	2.4555	-0.0365	-1.5084	2.2270	2.2325	-0.0055	-0.2465
55	2.2480	2.2896	-0.0416	-1.8522	2.2160	2.2569	-0.0409	-1.8450	2.0260	2.0593	-0.0333	-1.6441
60	2.0740	2.1092	-0.0352	-1.6994	2.0460	2.0796	-0.0336	-1.6424	1.8730	1.9042	-0.0312	-1.6643
65	1.9210	1.9478	-0.0268	-1.3944	1.9100	1.9209	-0.0109	-0.5702	1.7420	1.7648	-0.0228	-1.3092
70	1.7730	1.8029	-0.0299	-1.6845	1.7510	1.7784	-0.0274	-1.5647	1.6220	1.6393	-0.0173	-1.0645
75	1.6530	1.6724	-0.0194	-1.1759	1.6390	1.6501	-0.0111	-0.6788	1.5210	1.5259	-0.0049	-0.3213
80	1.5810	1.5547	0.0263	1.6604	1.5360	1.5344	0.0016	0.1071	1.4270	1.4232	0.0038	0.2637
85	1.4620	1.4483	0.0137	0.9379	1.4430	1.4296	0.0134	0.9282	1.3450	1.3301	0.0149	1.1097
90	1.3820	1.3518	0.0302	2.1884	1.3570	1.3346	0.0224	1.6503	1.2670	1.2453	0.0217	1.7103
95	1.3300	1.2640	0.0660	4.9606	1.3130	1.2482	0.0648	4.9317	1.1990	1.1681	0.0309	2.5794
100	1.2310	1.1841	0.0469	3.8089	1.2170	1.1696	0.0474	3.8972	1.1440	1.0975	0.0465	4.0656

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(b)

Fuels	Castor oil				B100				B75			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	444.0210	447.4503	-3.4293	-0.7723	22.5100	22.4987	0.0113	0.0502	14.4410	14.4875	-0.0465	-0.3222
35	331.8780	325.2707	6.6073	1.9909	18.3020	18.3048	-0.0028	-0.0155	12.1280	12.0417	0.0863	0.7116
40	241.4650	240.5161	0.9489	0.3930	15.0690	15.0900	-0.0210	-0.1392	10.1130	10.1277	-0.0147	-0.1456
45	178.8390	180.6987	-1.8597	-1.0399	12.5830	12.5928	-0.0098	-0.0782	8.6020	8.6120	-0.0100	-0.1167
50	135.9560	137.7938	-1.8378	-1.3518	10.6320	10.6292	0.0028	0.0260	7.3980	7.3984	-0.0004	-0.0058
55	104.7070	106.5502	-1.8432	-1.7604	9.0720	9.0674	0.0046	0.0502	6.4030	6.4166	-0.0136	-0.2128
60	81.9840	83.4733	-1.4893	-1.8166	7.8180	7.8120	0.0060	0.0772	5.6190	5.6147	0.0043	0.0762
65	65.3310	66.1998	-0.8688	-1.3299	6.8020	6.7927	0.0093	0.1372	4.9550	4.9539	0.0011	0.0228
70	52.7990	53.1074	-0.3084	-0.5842	5.9650	5.9574	0.0076	0.1266	4.3930	4.4047	-0.0117	-0.2668
75	43.1920	43.0667	0.1253	0.2902	5.2850	5.2671	0.0179	0.3378	3.9320	3.9448	-0.0128	-0.3267
80	35.8080	35.2805	0.5275	1.4733	4.6970	4.6920	0.0050	0.1062	3.5550	3.5569	-0.0019	-0.0543
85	30.1550	29.1792	0.9758	3.2358	4.2000	4.2092	-0.0092	-0.2197	3.2140	3.2275	-0.0135	-0.4202
90	25.5960	24.3511	1.2449	4.8636	3.7980	3.8011	-0.0031	-0.0820	2.9480	2.9460	0.0020	0.0683
95	21.9660	20.4948	1.4712	6.6975	3.4480	3.4539	-0.0059	-0.1701	2.7060	2.7040	0.0020	0.0743
100	19.0280	17.3876	1.6404	8.6208	3.1420	3.1566	-0.0146	-0.4645	2.5260	2.4948	0.0312	1.2343

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(b)

Fuels	B60				B50				B40			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	10.5180	10.5213	-0.0033	-0.0311	8.8060	8.8010	0.0050	0.0566	7.2700	7.2565	0.0135	0.1856
35	8.8880	8.8828	0.0052	0.0587	7.5030	7.5003	0.0027	0.0365	6.2470	6.2521	-0.0051	-0.0815
40	7.5800	7.5799	0.0001	0.0012	6.4490	6.4564	-0.0074	-0.1144	5.4130	5.4370	-0.0240	-0.4428
45	6.5340	6.5326	0.0014	0.0211	5.5990	5.6100	-0.0110	-0.1969	4.7450	4.7692	-0.0242	-0.5090
50	5.6800	5.6823	-0.0023	-0.0400	4.9150	4.9173	-0.0023	-0.0458	4.2420	4.2172	0.0248	0.5857
55	4.9860	4.9853	0.0007	0.0135	4.3420	4.3451	-0.0031	-0.0725	3.8050	3.7571	0.0479	1.2586
60	4.3930	4.4091	-0.0161	-0.3666	3.8670	3.8688	-0.0018	-0.0459	3.3430	3.3707	-0.0277	-0.8299
65	3.9300	3.9288	0.0012	0.0307	3.4700	3.4690	0.0010	0.0275	3.0280	3.0439	-0.0159	-0.5257
70	3.5290	3.5254	0.0036	0.1024	3.1340	3.1312	0.0028	0.0891	2.7760	2.7656	0.0104	0.3744
75	3.1960	3.1842	0.0118	0.3706	2.8560	2.8438	0.0122	0.4286	2.5170	2.5271	-0.0101	-0.4020
80	2.8950	2.8936	0.0014	0.0482	2.6390	2.5977	0.0413	1.5669	2.3510	2.3216	0.0294	1.2523
85	2.6440	2.6447	-0.0007	-0.0255	2.3780	2.3857	-0.0077	-0.3237	2.1360	2.1434	-0.0074	-0.3470
90	2.4300	2.4302	-0.0002	-0.0069	2.1850	2.2022	-0.0172	-0.7855	1.9890	1.9882	0.0008	0.0387
95	2.2460	2.2443	0.0017	0.0745	2.0350	2.0424	-0.0074	-0.3647	1.8440	1.8524	-0.0084	-0.4561
100	2.0760	2.0825	-0.0065	-0.3135	1.8930	1.9027	-0.0097	-0.5138	1.7280	1.7330	-0.0050	-0.2897

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(b)

Fuels	B30				B20				B10			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	5.9350	5.9341	0.0009	0.0146	4.8400	4.8315	0.0085	0.1759	3.9690	3.9686	0.0004	0.0109
35	5.1630	5.1635	-0.0005	-0.0102	4.2450	4.2549	-0.0099	-0.2330	3.5390	3.5475	-0.0085	-0.2388
40	4.5280	4.5322	-0.0042	-0.0924	3.7720	3.7760	-0.0040	-0.1069	3.2130	3.1912	0.0218	0.6778
45	4.0150	4.0103	0.0047	0.1172	3.3740	3.3751	-0.0011	-0.0339	2.8710	2.8878	-0.0168	-0.5859
50	3.5810	3.5753	0.0057	0.1594	3.0390	3.0370	0.0020	0.0657	2.6260	2.6278	-0.0018	-0.0668
55	3.2100	3.2099	0.0001	0.0033	2.7470	2.7498	-0.0028	-0.1019	2.4130	2.4035	0.0095	0.3940
60	2.8980	2.9007	-0.0027	-0.0947	2.5100	2.5043	0.0057	0.2288	2.2040	2.2090	-0.0050	-0.2279
65	2.6330	2.6374	-0.0044	-0.1678	2.2910	2.2931	-0.0021	-0.0896	2.0440	2.0395	0.0045	0.2205
70	2.4100	2.4117	-0.0017	-0.0709	2.1120	2.1103	0.0017	0.0783	1.8900	1.8910	-0.0010	-0.0514
75	2.2090	2.2171	-0.0081	-0.3671	1.9540	1.9514	0.0026	0.1309	1.7430	1.7603	-0.0173	-0.9897
80	2.0530	2.0484	0.0046	0.2236	1.8130	1.8126	0.0004	0.0247	1.6530	1.6447	0.0083	0.5027
85	1.9180	1.9014	0.0166	0.8649	1.6980	1.6906	0.0074	0.4367	1.5350	1.5421	-0.0071	-0.4632
90	1.7680	1.7727	-0.0047	-0.2664	1.5840	1.5830	0.0010	0.0628	1.4750	1.4507	0.0243	1.6475
95	1.6580	1.6595	-0.0015	-0.0920	1.4840	1.4877	-0.0037	-0.2510	1.3690	1.3689	0.0001	0.0042
100	1.5570	1.5596	-0.0026	-0.1649	1.3960	1.4030	-0.0070	-0.5024	1.2840	1.2956	-0.0116	-0.9008

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(b)

Fuels	B5				B2				Diesel			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	3.6660	3.6631	0.0029	0.0799	3.5940	3.5988	-0.0048	-0.1325	3.2190	3.2161	0.0029	0.0888
35	3.2770	3.2822	-0.0052	-0.1594	3.2280	3.2301	-0.0021	-0.0637	2.9010	2.9024	-0.0014	-0.0487
40	2.9600	2.9601	-0.0001	-0.0020	2.9370	2.9169	0.0201	0.6843	2.6270	2.6341	-0.0071	-0.2684
45	2.6860	2.6856	0.0004	0.0131	2.6380	2.6492	-0.0112	-0.4236	2.3940	2.4031	-0.0091	-0.3794
50	2.4540	2.4504	0.0036	0.1465	2.4190	2.4189	0.0001	0.0058	2.2270	2.2031	0.0239	1.0712
55	2.2480	2.2475	0.0005	0.0211	2.2160	2.2196	-0.0036	-0.1616	2.0260	2.0291	-0.0031	-0.1543
60	2.0740	2.0716	0.0024	0.1173	2.0460	2.0462	-0.0002	-0.0108	1.8730	1.8769	-0.0039	-0.2080
65	1.9210	1.9182	0.0028	0.1482	1.9100	1.8946	0.0154	0.8045	1.7420	1.7431	-0.0011	-0.0624
70	1.7730	1.7837	-0.0107	-0.6052	1.7510	1.7615	-0.0105	-0.5969	1.6220	1.6249	-0.0029	-0.1812
75	1.6530	1.6654	-0.0124	-0.7504	1.6390	1.6439	-0.0049	-0.2996	1.5210	1.5202	0.0008	0.0542
80	1.5810	1.5608	0.0202	1.2782	1.5360	1.5397	-0.0037	-0.2432	1.4270	1.4269	0.0001	0.0065
85	1.4620	1.4679	-0.0059	-0.4054	1.4430	1.4470	-0.0040	-0.2796	1.3450	1.3436	0.0014	0.1070
90	1.3820	1.3852	-0.0032	-0.2295	1.3570	1.3642	-0.0072	-0.5333	1.2670	1.2688	-0.0018	-0.1430
95	1.3300	1.3112	0.0188	1.4164	1.3130	1.2900	0.0230	1.7503	1.1990	1.2016	-0.0026	-0.2127
100	1.2310	1.2447	-0.0137	-1.1166	1.2170	1.2233	-0.0063	-0.5152	1.1440	1.1408	0.0032	0.2770

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(c)

Fuels	Castor oil				B100				B75			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	444.0210	439.6902	4.3308	0.9754	22.5100	21.7147	0.7953	3.5329	14.4410	13.9651	0.4759	3.2952
35	331.8780	329.0343	2.8437	0.8568	18.3020	18.3055	-0.0035	-0.0192	12.1280	12.0048	0.1232	1.0162
40	241.4650	247.3786	-5.9136	-2.4491	15.0690	15.4740	-0.4050	-2.6877	10.1130	10.3447	-0.2317	-2.2914
45	178.8390	186.8295	-7.9905	-4.4680	12.5830	13.1154	-0.5324	-4.2308	8.6020	8.9353	-0.3333	-3.8745
50	135.9560	141.7197	-5.7637	-4.2394	10.6320	11.1449	-0.5129	-4.8244	7.3980	7.7355	-0.3375	-4.5623
55	104.7070	107.9586	-3.2516	-3.1055	9.0720	9.4942	-0.4222	-4.6543	6.4030	6.7117	-0.3087	-4.8211
60	81.9840	82.5794	-0.5954	-0.7262	7.8180	8.1077	-0.2897	-3.7051	5.6190	5.8359	-0.2169	-3.8600
65	65.3310	63.4191	1.9119	2.9265	6.8020	6.9399	-0.1379	-2.0272	4.9550	5.0850	-0.1300	-2.6227
70	52.7990	48.8935	3.9055	7.3970	5.9650	5.9539	0.0111	0.1862	4.3930	4.4396	-0.0466	-1.0610
75	43.1920	37.8370	5.3550	12.3982	5.2850	5.1193	0.1657	3.1349	3.9320	3.8838	0.0482	1.2262
80	35.8080	29.3879	6.4201	17.9291	4.6970	4.4112	0.2858	6.0843	3.5550	3.4040	0.1510	4.2466
85	30.1550	22.9068	7.2482	24.0364	4.2000	3.8090	0.3910	9.3088	3.2140	2.9891	0.2249	6.9981
90	25.5960	17.9168	7.6792	30.0015	3.7980	3.2957	0.5023	13.2242	2.9480	2.6294	0.3186	10.8057
95	21.9660	14.0610	7.9050	35.9875	3.4480	2.8573	0.5907	17.1324	2.7060	2.3171	0.3889	14.3703
100	19.0280	11.0711	7.9569	41.8168	3.1420	2.4819	0.6601	21.0083	2.5260	2.0454	0.4806	19.0256

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(c)

Fuels	B60				B50				B40			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	10.5180	10.1442	0.3738	3.5538	8.8060	8.4877	0.3183	3.6147	7.2700	7.0020	0.2680	3.6861
35	8.8880	8.8376	0.0504	0.5674	7.5030	7.4553	0.0477	0.6355	6.2470	6.2073	0.0397	0.6360
40	7.5800	7.7163	-0.1363	-1.7987	6.4490	6.5622	-0.1132	-1.7554	5.4130	5.5134	-0.1004	-1.8550
45	6.5340	6.7519	-0.2179	-3.3342	5.5990	5.7878	-0.1888	-3.3715	4.7450	4.9063	-0.1613	-3.3997
50	5.6800	5.9202	-0.2402	-4.2296	4.9150	5.1147	-0.1997	-4.0637	4.2420	4.3740	-0.1320	-3.1122
55	4.9860	5.2015	-0.2155	-4.3229	4.3420	4.5285	-0.1865	-4.2964	3.8050	3.9064	-0.1014	-2.6637
60	4.3930	4.5790	-0.1860	-4.2350	3.8670	4.0169	-0.1499	-3.8772	3.3430	3.4947	-0.1517	-4.5368
65	3.9300	4.0387	-0.1087	-2.7660	3.4700	3.5695	-0.0995	-2.8670	3.0280	3.1316	-0.1036	-3.4198
70	3.5290	3.5687	-0.0397	-1.1249	3.1340	3.1774	-0.0434	-1.3843	2.7760	2.8107	-0.0347	-1.2497
75	3.1960	3.1590	0.0370	1.1565	2.8560	2.8331	0.0229	0.8012	2.5170	2.5267	-0.0097	-0.3836
80	2.8950	2.8013	0.0937	3.2376	2.6390	2.5303	0.1087	4.1194	2.3510	2.2748	0.0762	3.2423
85	2.6440	2.4882	0.1558	5.8918	2.3780	2.2634	0.1146	4.8183	2.1360	2.0510	0.0850	3.9780
90	2.4300	2.2138	0.2162	8.8975	2.1850	2.0278	0.1572	7.1930	1.9890	1.8519	0.1371	6.8905
95	2.2460	1.9728	0.2732	12.1648	2.0350	1.8195	0.2155	10.5898	1.8440	1.6745	0.1695	9.1905
100	2.0760	1.7607	0.3153	15.185	1.8930	1.6350	0.2580	13.6315	1.7280	1.5162	0.2118	12.2591

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7.* (Cont.).

(c)

Fuels	B30				B20				B10			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	5.9350	5.7310	0.2040	3.4380	4.8400	4.6748	0.1652	3.4126	3.9690	3.8581	0.1109	2.7947
35	5.1630	5.1244	0.0386	0.7480	4.2450	4.2187	0.0263	0.6192	3.5390	3.5191	0.0199	0.5610
40	4.5280	4.5903	-0.0623	-1.3752	3.7720	3.8134	-0.0414	-1.0975	3.2130	3.2147	-0.0017	-0.0543
45	4.0150	4.1190	-0.1040	-2.5903	3.3740	3.4525	-0.0785	-2.3279	2.8710	2.9409	-0.0699	-2.4342
50	3.5810	3.7024	-0.1214	-3.3891	3.0390	3.1307	-0.0917	-3.0169	2.6260	2.6941	-0.0681	-2.5931
55	3.2100	3.3333	-0.1233	-3.8419	2.7470	2.8431	-0.0961	-3.4983	2.4130	2.4713	-0.0583	-2.4176
60	2.8980	3.0058	-0.1078	-3.7212	2.5100	2.5857	-0.0757	-3.0158	2.2040	2.2700	-0.0660	-2.9927
65	2.6330	2.7147	-0.0817	-3.1032	2.2910	2.3549	-0.0639	-2.7903	2.0440	2.0876	-0.0436	-2.1346
70	2.4100	2.4554	-0.0454	-1.8855	2.1120	2.1477	-0.0357	-1.6901	1.8900	1.9223	-0.0323	-1.7095
75	2.2090	2.2242	-0.0152	-0.6865	1.9540	1.9613	-0.0073	-0.3742	1.7430	1.7722	-0.0292	-1.6749
80	2.0530	2.0175	0.0355	1.7285	1.8130	1.7934	0.0196	1.0797	1.6530	1.6357	0.0173	1.0468
85	1.9180	1.8326	0.0854	4.4538	1.6980	1.6420	0.0560	3.2996	1.5350	1.5114	0.0236	1.5366
90	1.7680	1.6668	0.1012	5.7234	1.5840	1.5052	0.0788	4.9779	1.4750	1.3981	0.0769	5.2132
95	1.6580	1.5180	0.1400	8.4436	1.4840	1.3814	0.1026	6.9156	1.3690	1.2947	0.0743	5.4294
100	1.5570	1.3842	0.1728	11.0963	1.3960	1.2692	0.1268	9.0801	1.2840	1.2001	0.0839	6.5317

Table B3. Error and percent relative error for kinematic viscosity of biodiesel blends (a) *Equation 5* (b) *Equation 6,* (c) *Equation 7*. (Cont.).

(c)

Fuels	B5				B2				Diesel			
T (°C)	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error	Experimental	Calculated	Error	Relative error
30	3.6660	3.5542	0.1118	3.0498	3.5940	3.4983	0.0957	2.6634	3.2190	3.1332	0.0858	2.6666
35	3.2770	3.2524	0.0246	0.7514	3.2280	3.2021	0.0259	0.8035	2.9010	2.8789	0.0221	0.7628
40	2.9600	2.9804	-0.0204	-0.6907	2.9370	2.9351	0.0019	0.0645	2.6270	2.6488	-0.0218	-0.8308
45	2.6860	2.7350	-0.0490	-1.8253	2.6380	2.6941	-0.0561	-2.1273	2.3940	2.4404	-0.0464	-1.9373
50	2.4540	2.5132	-0.0592	-2.4118	2.4190	2.4762	-0.0572	-2.3655	2.2270	2.2512	-0.0242	-1.0872
55	2.2480	2.3123	-0.0643	-2.8620	2.2160	2.2789	-0.0629	-2.8384	2.0260	2.0793	-0.0533	-2.6300
60	2.0740	2.1302	-0.0562	-2.7108	2.0460	2.0999	-0.0539	-2.6361	1.8730	1.9228	-0.0498	-2.6585
65	1.9210	1.9649	-0.0439	-2.2827	1.9100	1.9374	-0.0274	-1.4338	1.7420	1.7802	-0.0382	-2.1903
70	1.7730	1.8145	-0.0415	-2.3388	1.7510	1.7895	-0.0385	-2.2006	1.6220	1.6500	-0.0280	-1.7240
75	1.6530	1.6775	-0.0245	-1.4837	1.6390	1.6549	-0.0159	-0.9678	1.5210	1.5310	-0.0100	-0.6558
80	1.5810	1.5527	0.0283	1.7929	1.5360	1.5320	0.0040	0.2582	1.4270	1.4221	0.0049	0.3446
85	1.4620	1.4386	0.0234	1.5976	1.4430	1.4199	0.0231	1.6035	1.3450	1.3223	0.0227	1.6871
90	1.3820	1.3344	0.0476	3.4433	1.3570	1.3173	0.0397	2.9262	1.2670	1.2308	0.0362	2.8592
95	1.3300	1.2390	0.0910	6.8414	1.3130	1.2234	0.0896	6.8253	1.1990	1.1467	0.0523	4.3619
100	1.2310	1.1516	0.0794	6.4519	1.2170	1.1373	0.0797	6.5485	1.1440	1.0694	0.0746	6.5218