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Measurements, Correlations and Comparison of Biodiesel Blend Properties with three Commercial Diesel Fuels, Kerosene and Benzene

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Abstract

In this experimental work, waste mixture of sunflower and rapeseed (WSRME), waste canola (WCME), waste sunflower (WSME), hazelnut (HNME) and refined canola oil (RCME) methyl ester biodiesel were prepared via transesterification process. Mixtures of biodiesel with three commercial diesel fuels, namely, petroleum diesel fuel, ultra-low sulfur diesel winter (ULSDW) and ultra-low sulfur diesel summer (ULSDS) were used to study the variation of density and kinematic viscosity as a function of volume fraction of biodiesel. It has been found that the physical-chemical properties are within the range of different specification standards. Engine problems with the use of biodiesel–fuel blends that contain higher percentages of the biodiesel need to be solved in order to utilize the advantages of biodiesel in environmental and economic ways. The mentioned problems can also be solved by blending biodiesel with another low density or viscosity fuel such as kerosene and benzene. In the present work, biodiesel have been blended with kerosene and benzene with various volume fractions. Furthermore, the cold flow properties like cloud point (CP) and pour point (PP) of biodiesel blends were also examined. The results showed that overall physico-chemical characteristics of blending fuel were reduced by the increasing of kerosene and benzene concentrations. Consequently, kerosene and benzene can play a role as a diluents agent to reduce the characteristic of the cold flow properties of biodiesel. Moreover, correlations were developed for predicting temperature dependent viscosity and densities based on the volume fraction of biodiesel.

Keywords: Benzene; Cold flow properties; Density; Diesel fuel; Kerosene; Kinematic viscosity.

INTRODUCTION

Replacing fossil fuels with renewable non-fossil biomass fuels presents a promising solution to the upcoming energy crisis [1–5].When considering the process of consolidation that is currently happening with renewable energy, biodiesels are an appropriate choice, offering alternatives to solve economic, social, and environmental problems [6–7]. However, their performance at low temperature affects commercial viability, causing problems not only when starting an engine but performance during normal operating conditions [8–10]. Biodiesel is described as a fuel comprising mono-alkyl esters of long-chain fatty acid derived from vegetable oils or animal fats. As an alternative to petroleum-based diesel fuel, biodiesel is renewable and biodegradable. It significantly reduces particulate matter, hydrocarbon, and carbon monoxide emissions [11–12] from combustion. Biodiesel is receiving increasing attention as an alternative fuel for diesel engines. Biodiesel provides exhaust emission benefits compared to diesel fuel [13–14], but perhaps its greatest benefit is that it can be used in existing engines without modification. Further, it requires no changes to the existing fuel distribution and storage infrastructure [15]. Researchers have developed various methods of preparing biodiesel such as transesterification with the help of basic, acidic and enzymatic catalysts, supercritical methanol transesterification, simultaneous reaction of transesterification and cracking [16–18].

Biodiesel fuels are generally more viscous than diesel fuels. 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].

Density is another important property of biodiesel. It is defined as its mass per unit volume, whereas the specific gravity of biodiesel is the ratio of its density and the density of water as reference compound. The increase in biodiesel density can affect the operation of the fuel injection system due to the delivery of a slightly greater mass of fuel in the volume metering equipment [20].

Numerous empirical correlations have been developed, which relate various performance parameters. The effect on viscosity and density of blending biodiesel and conventional diesel fuel were investigated by scientists, and equations were derived that allow the calculation of the viscosity and density of such blends. These equations can predict the viscosity or density of the blend using biodiesel's molar and volume fraction and temperature [21-30]. Accurate prediction methods are of great practical value in predicting the kinematic viscosity and density of biodiesel or FAMEs, and relevant studies can be found in the recent literature [21-30]. Also, accurate prediction methods are of great practical value in predicting the kinematic viscosity and density of biodiesel or FAMEs, and relevant studies can be found in the recent literature [22-29].

In this study, waste mixture of sunflower and rapeseed, waste canola oil, waste sunflower oil, hazelnut oil and refine canola oil biodiesel (WSRME, WCME, WSME, HNME and RCME, respectively) were produced by transesterification process. These biodiesel were blended with three commercially available fuels, namely, diesel I (petroleum diesel fuel), diesel II (ultra-low sulfur diesel winter (ULSDW) and diesel III (ultra-low sulfur diesel summer (ULSDS) at the various volume fraction of biodiesel. In addition, in this work the kinematic viscosity, density and cold flow properties in terms of CP and PP were investigated. The main objective of this study is to test the feasibility of biodiesel in cold climate such as in Cyprus and suggest an appropriate solution for the future of biofuel. As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel is widely accepted as comparable fuel to diesel in diesel engines. This is due to several factors like decreasing the dependence on imported petroleum, reducing global warming, increasing lubricity, and reducing substantially the exhaust emissions from diesel engine. However, there is a major disadvantage in the use of biodiesel as it has lower heating value, higher density and higher viscosity, higher fuel consumption and higher NOX emission, which limits its application. Here fuel additives become essential and indispensable tools not only to minimize these drawbacks but also generate specified products to meet the regional and international standards. Fuel additives can contribute towards fuel economy and emission reduction either directly or indirectly. The problem that was aimed to be solved is to making possible the usability of high percentages of biodiesel in unmodified diesel engine. Effect of kerosene and commercial additive on cold flow behavior of this biodiesel was studied [31]. Kerosene and addition to biodiesel improved the flow properties and reduced the kinematic viscosity of the fluid. In other works, it was concluded that the flow properties of the biodiesel, such as kinematic viscosity, cloud point, and pour point were improved with kerosene [32, 33]. Therefore, the present work was carried out to evaluate the kerosene and benzene fuel along with its mixtures in biodiesel as fuels for diesel engines. The paper investigates the effects of certain amounts of kerosene–biodiesel blends and benzene- kerosene–biodiesel blends on kinematic viscosity, density, Cloud point (CP) and Pour Point (PP) of blends. Moreover, in this study, the most widely used expressions in the literature predicting the viscosity and density of biodiesel produced from vegetable oil and waste vegetable oils mixture with five different commercial fuels which we produced with different volume fractions were examined, in order to establish whether they can predict the blended viscosity of the mixtures.

MATERIALS AND METHODS

Fuels

Five different biodiesel; WSRME, WCME, WSME, HNME and RCME, were transesterified fatty acid methyl ester of mixture of waste sunflower and rapeseeds, waste canola, waste sunflower, refined canola and hazelnut vegetable oils and were collected from local area. The physico-chemical analysis performed for biodiesels are described in Table 1. Additionally, Table 2 shows the data obtained by gas chromatographic to determine the composition of methylic esters in each biodiesel. The biodiesel are blended with three different commercially available diesel fuels, diesel I (petroleum diesel fuel), diesel II, (ULSDW) and diesel III, (ULSDS), kerosene and benzene fuel. The properties of these fuels are presented in Table 3. A series of volume fractions (VF) blends was prepared by blending each fuel with all biodiesel. The blending method followed was weighing the samples by an analytic balance with uncertainty equal to ±0.0001 g. after that the samples were perfectly mixed by a magnetic stirrer prior to experimental measurement of biodiesel blends properties.

Table 1 Biodiesels properties and corresponding standard values

Fuel Property	Unit	Test method	Standard specifications	WSRME	WCME	WSME
Flash point	℃	ASTM D93	58 -	130	157.5	165
Cloud point	℃	ASTM D5771	….	-1	-2	17
Cetane number	-	ASTM D2500	….	54.7	56.3	51.6
CFPP	℃	EN 116	….	-3	-5	14
Pour point	℃	ASTM D97	….	-6	-10	9
Density @ 15℃	kg/m^3	ASTM D854	860-….	883	895.89	895.54
Viscosity @ 40℃	mm^2/s	ASTM D 455	1.90–6.00	4.67	4.55	4.62
Fuel Property	**Unit**	**Test method**	**Standard specifications**	**HNME**	**RCME**	
Flash point	℃	ASTM D93	58 -	175	177	
Cloud point	℃	ASTM D5771	….	-11	-4	
Cetane number	-	ASTM D2500	….	53	54.3	
CFPP	℃	EN 116	….	-14	-8	
Pour point	℃	ASTM D97	….	-17	-12	
Density @ 15℃	kg/m^3	ASTM D854	860-….	875	884	
Viscosity @ 40℃	mm^2/s	ASTM D 455	1.90–6.00	4.68	4.53	

Table 2. Fatty acid composition of all biodiesel

Fatty acid	Structure	WSRME	WCME	WSME	HNME	RCME
Caprylic acid	C8:0	0.00	0.00	0.05	0.00	0.00
Capric acid	C10:0	0.00	0.00	0.33	0.00	0.00
Lauric acid	C12:0	0.00	0.08	1.18	0.00	0.00
Myrictic acid	C14:0	0.00	0.00	0.10	0.00	0.05
Palmitic acid	C16:0	0.24	5.63	37.29	9.66	4.14
Methylpalmitoleate	C16:1	0.09	0.00	0.00	0.00	0.20
Stearic acid	C18:0	36.18	1.57	4.04	0.00	1.91
Oleic acid	C18:1	2.75	62.97	40.42	76.13	58.90
Linoleic acid	C18:2	36.17	21.34	17.84	13.04	20.57
Linolenic acid	C18:3	3.99	6.99	0.18	0.20	9.34
Arachidic acid	C20:0	0.51	0.46	0.00	0.24	0.63
Eicosenoic acid	C20:1	0.44	1.04	0.00	0.34	1.35
Methyl behenate	C22:0	0.14	0.00	0.00	0.39	0.37
Methyl erucate	C22:1	0.00	0.00	0.00	0.00	0.06
Methyl lignocerate	C24:0	0.13	0.00	0.00	0.00	0.00

Table 3. Fuels properties and corresponding standard values

Fuel Property	Unit	Test method	Standard specifications	Diesel I	Diesel II (ULSDW)	Diesel III (ULSDS)
Flash point	℃	ASTM D93	58 -	64	68	64
		IP 170	38 - ...	-	-	-
Cloud point	℃	ASTM D5771	….	-	-	-
Cetane number	-	ASTM D613	51.0- ...	51	55	54
CFPP	℃	IP 309	... - -17	-6	-20	-8
Pour point	℃	ASTM D5950	….	-	-	-
Density @ 15℃	kg/m^3	ASTM D4052	800-880	840	832.5	825.8
Viscosity @ 40℃	mm^2/s	ASTM D 455	1.90–6.00	3.4	3	2.7
Flash point	℃	ASTM D93	58 -	-	-	
		IP 170	38 - ...	47	-	
Cloud point	℃	ASTM D5771	….	-	-	
Cetane number	-	ASTM D613	51.0- ...	-	-	
CFPP	℃	IP 309	... - -17	-	-	
Pour point	℃	ASTM D5950	….	-	-	
Density @ 15℃	kg/m^3	ASTM D4052	800-880	798.6	737.2	
Viscosity @ 40℃	mm^2/s	ASTM D 455	1.90–6.00	1.173	0.537	

Kinematic Viscosity

The kinematic viscosity measurement was carried out for each sample at 40°C by using an Ubbelohde viscometer according to ASTM Standard D-445. For kinematic viscosity determination, the time of a known volume of the sample flowing under gravity to pass through the viscometer tube (efflux time) was multiplied by the viscometer constant which was obtained from calibration by the manufacturer. To ensure precise and stable temperature control during measurements, a digital temperature controller resistance was used to measure the temperature. A uniform temperature inside the silicon oil bath was attained. However, the mixer enabled the regulation of the temperature of a heated oil bath containing the viscometer by means of an electric heater. The measurements for viscosities were done three times for each sample and the results were averaged.

Density

Pycnometer with a bulb capacity of 25ml was used to measure the density of biodiesel in kg/m^3 following the ASTM standard D-4052. The weighing was done by using electronic balance with a precision of ± 0.1mg. Each sample was tested three times, and the average density was calculated.

Low Temperature Properties

The determinations of cloud point (CP) and pour point (PP) were made according to automated methods ASTM D2500 and ASTM D97, respectively. For a greater degree of accuracy, PP measurements were done with a resolution of 1 °C instead of the specified 3°C increment.

RESULTS AND DISCUSSION

The experimental data of kinematic viscosity and density at 40°C and 15°C, respectively, averaged for all test fuels were listed in section 3.1 and 3.2. Also, the effects of various volume fractions of test fuels on kinematic viscosity and density were investigated. Moreover, empirical correlations obtained from previous studied were examined and tested for fuels and the developed equations are compared with them. Numerous measurements took place in order to verify that the experimental values of density and viscosity were adequate. To demonstrate that the presented results ensure the required accuracy, a number of plots were prepared. Viscosity and Density were plotted against the percentage of biodiesel in the blends.

Effect of Volume Fraction of Biodiesel on Kinematic Viscosity of Blends

The results of kinematic viscosity for the studied mixtures in this work are reported in Table 4. It is observed that the kinematic viscosities of biodiesel vary in the range of 4.68 - 4.53 mm^2/s and are higher than those of fuels, 3.40-0.54 mm^2/s, at 40°C. The obtained kinematic viscosity data for biodiesel correspond with the recommended ASTM D 455 values: 1.9 - 6 mm^2/s at 40°C. It is observed that the kinematic viscosity of all studied blends of biodiesel with diesel fuel, benzene or toluene increases with the increase of biodiesel content. Data from Table 4 shows the viscosity of WSRME + diesel I blends with no more than 60 vol% biodiesel is in accordance with standard demand for diesel fuel (ASTM D975 recommended values: 1.9–4.10 mm^2/s at 40 °C). While, viscosity of WSME + diesel I, HNME + diesel I, RCME + diesel I blends with no more than 55 vol% (volume basis) biodiesel is in accordance with standard demand for diesel fuel (ASTM D975 recommended values: 1.9–4.10 mm^2/s at 40 °C). Biodiesel addition to kerosene and benzene increase the kinematic viscosity of the blend, as shown in Table 4. It is noticed that kinematic viscosity of kerosene and benzene with biodiesel blends content higher than 45 vol% and 70 vol% (volume basis), respectively, fulfill biodiesel standard requirement.

Effect of Volume Fraction of Biodiesel on Density of Blends

Table 5 is tabulated the density values at 15°C for different biodiesel blends with five different fuels at different percentage of volume factions (VF) of biodiesel. It is observed that if the experimental results of biodiesel fuel blends with diesel I, diesel II and diesel III compared with specification diesel fuel standard (ASTM D4052) range between 800 and 880 kg/m^3 overall density results meet the minimum and maximum standard or specification requirements of diesel fuel. Moreover, density of biodiesel blend to kerosene or benzene decreases as addition of kerosene or benzene increased or when vol % of kerosene or benzene increased in the mixture of blend. The density of WSRME + kerosene blends with higher than 25 vol% (volume basis) biodiesel is in accordance with standard demand for diesel fuel (ASTM D4052 recommended values: 800 and 880 kg/m^3 at 15 °C). Also, it is noticed that the density of WCME + kerosene and WSME + kerosene blend with no more than 85 vol% kerosene is is in accordance with standard demand for diesel fuel. Additionally, the density of HOME and RCME blend with content less than 80% vol% (volume basis), fulfill biodiesel standard requirement. Additionally, density of benzene blends with WSRME content higher than 65 vol% (volume basis), fulfill diesel standard requirement. Moreover, the density of WCME and WSME blend with benzene content higher than 50 vol% fulfill biodiesel standard requirements. In addition, it is shown that when benzene blends HNME and RCME content higher than 55% vol fulfill diesel standard requirement.

Table 4. Measured kinematic viscosity values (mm^2/s) of fuel-biodiesel blends at 40^{o}C

Fuel	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**Fuel**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Diesel I	**0**	3.40	3.40	3.40	3.40	3.40	Diesel II	3.00	3.00	3.00	3.00	3.00
	0.05	3.50	3.46	3.47	3.54	3.52		3.08	3.09	3.10	3.16	3.14
	0.07	3.51	3.56	3.57	3.64	3.62		3.16	3.17	3.18	3.24	3.21
	0.1	3.53	3.57	3.58	3.65	3.63		3.24	3.25	3.26	3.31	3.29
	0.15	3.57	3.59	3.60	3.67	3.64		3.32	3.33	3.34	3.39	3.37
	0.2	3.62	3.63	3.64	3.71	3.68		3.36	3.41	3.42	3.48	3.46
	0.25	3.67	3.68	3.69	3.76	3.74		3.39	3.45	3.46	3.51	3.49
	0.3	3.71	3.73	3.74	3.81	3.79		3.45	3.48	3.49	3.55	3.53
	0.35	3.72	3.77	3.78	3.85	3.83		3.49	3.54	3.55	3.61	3.59
	0.4	3.75	3.78	3.79	3.86	3.84		3.52	3.58	3.59	3.65	3.62
	0.45	3.78	3.81	3.82	3.89	3.87		3.58	3.61	3.62	3.68	3.66
	0.5	3.97	3.84	3.85	3.92	3.90		3.60	3.67	3.68	3.74	3.72
	0.55	4.03	4.03	4.04	4.11	4.09		3.62	3.69	3.70	3.76	3.74
	0.6	4.10	4.09	4.11	4.17	4.15		3.67	3.71	3.72	3.78	3.76
	0.65	4.13	4.16	4.18	4.25	4.22		3.73	3.76	3.77	3.83	3.81
	0.7	4.22	4.19	4.21	4.28	4.25		3.82	3.82	3.83	3.89	3.87
	0.75	4.31	4.28	4.29	4.36	4.33		3.97	3.91	3.92	3.98	3.96
	0.8	4.35	4.37	4.38	4.45	4.43		4.13	4.06	4.07	4.13	4.10
	0.85	4.42	4.41	4.42	4.49	4.47		4.19	4.22	4.23	4.29	4.27
	0.9	4.44	4.48	4.49	4.56	4.54		4.30	4.28	4.29	4.35	4.33
	0.95	4.61	4.50	4.51	4.58	4.55		4.34	4.39	4.40	4.46	4.44
	1	4.67	4.55	4.62	4.68	4.53		4.67	4.55	4.62	4.68	4.53
Fuel	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**Fuel**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Diesel III	**0**	2.70	2.70	2.70	2.70	2.70	Kerosene	1.17	1.17	1.17	1.17	1.17
	0.05	2.74	2.79	2.80	2.80	2.78		1.24	1.21	1.22	1.22	1.21
	0.07	2.76	2.82	2.83	2.84	2.82		1.27	1.28	1.28	1.29	1.28
	0.1	2.79	2.85	2.86	2.86	2.84		1.31	1.31	1.31	1.32	1.31
	0.15	2.84	2.87	2.88	2.89	2.87		1.40	1.35	1.36	1.36	1.35
	0.2	2.93	2.92	2.93	2.94	2.92		1.48	1.44	1.45	1.45	1.44
	0.25	3.04	3.02	3.03	3.03	3.01		1.56	1.52	1.52	1.53	1.52
	0.3	3.11	3.12	3.13	3.14	3.12		1.65	1.60	1.61	1.61	1.60
	0.35	3.21	3.19	3.20	3.21	3.19		1.84	1.69	1.70	1.70	1.69
	0.4	3.23	3.30	3.31	3.32	3.30		2.00	1.88	1.89	1.89	1.88
	0.45	3.26	3.32	3.33	3.34	3.32		2.10	2.04	2.04	2.05	2.04
	0.5	3.28	3.34	3.35	3.36	3.34		2.23	2.14	2.15	2.15	2.14
	0.55	3.32	3.36	3.37	3.38	3.36		2.28	2.27	2.27	2.28	2.27
	0.6	3.37	3.41	3.42	3.42	3.40		2.50	2.32	2.33	2.33	2.32
	0.65	3.41	3.46	3.47	3.48	3.46		2.57	2.54	2.55	2.55	2.54
	0.7	3.43	3.49	3.50	3.51	3.49		2.70	2.61	2.61	2.61	2.61
	0.75	3.44	3.51	3.52	3.53	3.51		2.83	2.74	2.75	2.75	2.74
	0.8	3.64	3.53	3.54	3.55	3.53		3.10	2.87	2.88	2.88	2.87
	0.85	3.71	3.72	3.73	3.74	3.72		3.21	3.14	3.14	3.15	3.14
	0.9	3.76	3.80	3.81	3.81	3.79		3.57	3.26	3.26	3.26	3.25
	0.95	3.96	3.85	3.86	3.87	3.85		3.92	3.61	3.62	3.62	3.61
	1	4.67	4.55	4.62	4.68	4.53		4.67	4.55	4.62	4.68	4.53

Table 4. Continued

Diesels	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Benzene	**0**	0.54	0.54	0.54	0.54	0.54	**0.5**	1.26	1.16	1.16	1.16	1.16
	0.05	0.58	0.57	0.57	0.57	0.57	**0.55**	1.39	1.30	1.30	1.30	1.30
	0.07	0.59	0.61	0.61	0.61	0.61	**0.6**	1.61	1.42	1.42	1.43	1.42
	0.1	0.62	0.62	0.63	0.63	0.62	**0.65**	1.80	1.64	1.64	1.64	1.64
	0.15	0.71	0.65	0.65	0.65	0.65	**0.7**	2.08	1.83	1.84	1.84	1.83
	0.2	0.76	0.74	0.74	0.74	0.74	**0.75**	2.40	2.11	2.11	2.12	2.11
	0.25	0.83	0.79	0.80	0.80	0.79	**0.8**	2.62	2.43	2.43	2.44	2.43
	0.3	0.94	0.86	0.87	0.87	0.86	**0.85**	2.90	2.65	2.65	2.65	2.65
	0.35	0.96	0.97	0.97	0.97	0.97	**0.9**	3.25	2.93	2.93	2.93	2.93
	0.4	1.02	0.99	0.99	0.99	0.99	**0.95**	3.70	3.28	3.28	3.29	3.28
	0.45	1.13	1.05	1.05	1.05	1.05	**1**	4.67	4.55	4.62	4.68	4.53

Effect of Volume Fraction of Biodiesel on Density of Blends

Cloud points are useful as fuel quality control specifications for refiners when blending fuels during the cold climate, also as low temperature operability indicators for diesel-powered operators when using in cold ambient temperatures. The cloud point is a good parameter for quality control in the operation of diesel engines in low temperatures [34].

The characteristic results of cloud point values for the biodiesel blended fuels with different commercial fuels are shown in Table 6. The results revealed that cloud point mixtures of biodiesel and diesel I, II and III with 0%, 25%, 50%, 75% and 100% by volume of biodiesel are in range of cloud point of diesel fuels and cloud point of pure biodiesel. Moreover, the results showed that the cloud point of kerosene and benzene with 80% by volume of biodiesel is increased as the percentage of kerosene or benzene increase in the mixture.

The difference of those results is due to their high degree of saturation. Saturated fatty acids have higher melting points and temperatures of crystallization and in cold temperature they will crystallize before the mono-unsaturated and polyunsaturated fatty acids [35].

Table 5. Measured density values (kg/m^3) of fuel-biodiesel blends at 15ºC

Diesels	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**Diesels**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Diesel I	**0**	822.0	822.0	822.0	822.0	822.0	Diesel II	816.8	816.8	816.8	816.8	816.8
	0.05	824.1	825.4	825.5	824.6	825.0		819.0	820.4	820.6	819.6	820.0
	0.07	824.9	828.8	829.0	827.2	827.9		819.8	824.0	824.3	822.4	823.2
	0.1	826.1	832.1	832.5	829.8	830.9		821.1	827.6	828.1	825.1	826.4
	0.15	828.1	835.5	836.0	832.4	833.8		823.3	831.2	831.8	827.9	829.6
	0.2	830.1	838.8	839.5	835.0	836.8		825.4	834.8	835.6	830.7	832.8
	0.25	832.2	842.2	843.0	837.5	839.7		827.6	838.4	839.3	833.5	836.0
	0.3	834.2	845.5	846.5	840.1	842.7		829.7	842.0	843.1	836.2	839.2
	0.35	836.3	848.9	850.0	842.7	845.6		831.9	845.6	846.8	839.0	842.4
	0.4	838.3	852.3	853.5	845.3	848.6		834.1	849.2	850.6	841.8	845.6
	0.45	840.4	855.6	857.0	847.9	851.5		836.3	852.8	854.3	844.5	848.8
	0.5	842.4	859.0	860.5	850.5	854.5		838.4	856.4	858.1	847.3	852.0
	0.55	844.5	862.3	864.0	853.0	857.4		840.6	860.0	861.8	850.1	855.2
	0.6	846.6	865.7	867.5	855.6	860.4		842.8	863.5	865.6	852.8	858.4
	0.65	848.6	869.0	871.0	858.2	863.3		845.0	867.1	869.3	855.6	861.6
	0.7	850.7	872.4	874.5	860.8	866.3		847.3	870.7	873.1	858.4	864.8
	0.75	852.8	875.8	878.0	863.4	869.2		849.5	874.3	876.8	861.2	868.0
	0.8	854.9	879.1	881.5	866.0	872.2		851.7	877.9	880.5	863.9	871.2
	0.85	857.0	882.5	885.0	868.5	875.1		853.9	881.5	884.3	866.7	874.4
	0.9	859.1	885.8	888.5	871.1	878.1		856.2	885.1	888.0	869.5	877.6
	0.95	861.2	889.2	892.0	873.7	881.0		858.4	888.7	891.8	872.2	880.8
	1	864.4	895.9	895.5	875.0	884.0		864.4	895.9	895.5	875.0	884.0

Diesels	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**Diesels**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Diesel III	**0**	810.5	810.5	810.5	810.5	810.5	Kerosene	781.1	781.1	781.1	781.1	781.1
	0.05	812.9	814.4	814.4	813.6	813.9		784.9	786.3	786.3	785.4	785.8
	0.07	813.9	818.3	818.3	816.7	817.2		786.4	791.6	791.5	789.7	790.5
	0.1	815.3	822.2	822.1	819.7	820.6		788.6	796.8	796.7	793.9	795.2
	0.15	817.8	826.1	826.0	822.8	823.9		792.4	802.0	801.9	798.2	799.8
	0.2	820.2	829.9	829.9	825.9	827.2		796.2	807.2	807.1	802.5	804.5
	0.25	822.6	833.8	833.7	829.0	830.6		800.0	812.4	812.3	806.7	809.2
	0.3	825.0	837.7	837.6	832.0	833.9		803.9	817.6	817.5	811.0	813.9
	0.35	827.5	841.6	841.4	835.1	837.3		807.7	822.9	822.7	815.3	818.5
	0.4	829.9	845.5	845.3	838.2	840.6		811.6	828.1	827.9	819.5	823.2
	0.45	832.4	849.3	849.2	841.2	843.9		815.5	833.3	833.1	823.8	827.9
	0.5	834.9	853.2	853.0	844.3	847.3		819.4	838.5	838.3	828.1	832.6
	0.55	837.3	857.1	856.9	847.4	850.6		823.3	843.7	843.5	832.3	837.2
	0.6	839.8	861.0	860.8	850.4	853.9		827.3	848.9	848.7	836.6	841.9
	0.65	842.3	864.9	864.6	853.5	857.3		831.2	854.2	853.9	840.9	846.6
	0.7	844.8	868.7	868.5	856.6	860.6		835.2	859.4	859.1	845.1	851.3
	0.75	847.3	872.6	872.4	859.7	864.0		839.2	864.6	864.3	849.4	855.9
	0.8	849.8	876.5	876.2	862.7	867.3		843.3	869.8	869.5	853.7	860.6
	0.85	852.3	880.4	880.1	865.8	870.6		847.3	875.0	874.7	857.9	865.3
	0.9	854.8	884.3	883.9	868.9	874.0		851.4	880.2	879.9	862.2	870.0
	0.95	857.4	888.1	887.8	871.9	877.3		855.4	885.5	885.1	866.5	874.6
	1	864.4	895.9	895.5	875.0	884.0		864.4	895.9	895.5	875.0	884.0

Table 5. Continued

Diesels	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**	**VF**	**WSRME**	**WCME**	**WSME**	**HNME**	**RCME**
Benzene	**0**	713.1	713.1	713.1	713.1	713.1	**0.5**	780.9	804.5	804.3	794.1	798.6
	0.05	719.6	721.4	721.4	720.5	720.9	**0.55**	788.1	812.8	812.6	801.4	806.3
	0.07	722.3	729.7	729.7	727.8	728.7	**0.6**	795.3	821.1	820.9	808.8	814.1
	0.1	726.2	738.1	738.0	735.2	736.4	**0.65**	802.5	829.4	829.2	816.1	821.9
	0.15	732.8	746.4	746.3	742.6	744.2	**0.7**	809.8	837.7	837.5	823.5	829.6
	0.2	739.5	754.7	754.6	749.9	752.0	**0.75**	817.2	846.0	845.8	830.9	837.4
	0.25	746.3	763.0	762.9	757.3	759.7	**0.8**	824.7	854.4	854.1	838.2	845.2
	0.3	753.1	771.3	771.2	764.6	767.5	**0.85**	832.2	862.7	862.4	845.6	852.9
	0.35	759.9	779.6	779.5	772.0	775.3	**0.9**	839.8	871.0	870.7	852.9	860.7
	0.4	766.9	787.9	787.8	779.3	783.0	**0.95**	847.5	879.3	879.0	860.3	868.5
	0.45	773.9	796.2	796.0	786.7	790.8	**1**	864.4	895.9	895.5	875.0	884.0

In addition, the saturated acid esters have a very significant effect on the cold flow of biodiesel; in particular, biodiesel with higher percentages of saturated fatty esters has higher cloud points [36]. Pour point and cloud point have been routinely used to characterize the cold flow operability of diesel fuels in the petroleum industry. Pour points are useful or a good indicator for characterizing the suitably of a fuel for large storage and pipeline distributions [34]. The results revealed (Table 7) that pour point mixtures of biodiesel and diesel I, II and III with 0%, 25%, 50%, 75% and 100% by volume of biodiesel are in range of pour point of diesel fuels and pure biodiesel. Moreover, from the Table 7, it was observed that pour point get regularly decreases as increasing proportion biodiesel-kerosene blend and biodiesel-benzene blend. Also, it is noticed that addition of kerosene and benzene can reduce the pour point of biodiesel.

Table 6. Cloud point of the mixture of five biodiesel and five different fuels with various volume fraction of biodiesel

VF	Diesel I					VF	Diesel II				
	WSRME	WCME	WSME	HNME	RCME		WSRME	WCME	WSME	HNME	RCME
0	-4.0	-4.0	-4.0	-4.0	-4.0	**0**	-15.0	-15.0	-15.0	-15.0	-15.0
0.25	-3.0	-4.1	-1.4	-6.0	-5.2	**0.25**	-12.0	-4.1	-10.1	-22.5	-19.5
0.5	-2.5	-4.3	6.3	-7.2	-6.6	**0.5**	-9.0	-4.3	5.6	-27.0	-24.8
0.75	-2.2	-4.5	9.8	-10.0	-7.0	**0.75**	-5.0	-4.5	9.8	-37.5	-26.3
1	-1.0	-5.0	14.0	-14.0	-8.0	**1**	-1.0	-5.0	14.0	-14.0	-8.0

VF	Diesel II					VF	Kerosene				
	WSRME	WCME	WSME	HOME	RCME		WSRME	WCME	WSME	HNME	RCME
0	-6.0	-6.0	-6.0	-6.0	-6.0	**0.8**	-2.8	-8.5	2.1	-23.1	-13.6
0.25	-4.8	-5.5	3.6	-7.8	-6.6	**0.85**	-2.5	-7.8	5.6	-21.7	-12.4
0.5	-3.6	-5.4	5.6	-10.5	-6.9	**0.9**	-2.2	-6.5	8.4	-18.2	-10.4
0.75	-1.8	-5.2	9.8	-12.6	-7.5	**0.95**	-1.9	-5.8	11.9	-16.1	-9.2
1	-1.0	-5.0	14.0	-14.0	-8.0	**1**	-1.0	-5.0	14.0	-14.0	-8.0

VF	Benzene				
	WSRME	WCME	WSME	HNME	RCME
0.8	-3.1	-9.3	0.7	-25.9	-15.2
0.85	-2.7	-8.9	2.8	-24.9	-14.4
0.9	-2.5	-7.5	6.4	-21.0	-12.0
0.95	-1.6	-6.3	9.8	-17.5	-10.0
1	-1.0	-5.0	14.0	-14.0	-8.0

Table 7. Pour point of the mixture of five biodiesel and five different fuels with various volume fraction of biodiesel

VF	Diesel I					VF	Diesel II				
	WSRME	WCME	WSME	HNME	RCME		WSRME	WCME	WSME	HNME	RCME
0	-11.0	-11.0	-11.0	-11.0	-11.0	**0**	-25.0	-25.0	-25.0	-25.0	-25.0
0.25	-8.8	-10.2	-9.0	-12.1	-9.9	**0.25**	-20.0	-20.3	-18.8	-21.3	-21.0
0.5	-7.5	-10.0	-0.9	-14.5	-10.9	**0.5**	-15.0	-16.4	-9.4	-19.1	-17.9
0.75	-6.7	-8.0	6.3	-15.2	-11.4	**0.75**	-8.3	-13.3	-1.9	-18.2	-13.4
1	-6.0	-10.0	9.0	-17.0	-12.0	**1**	-6.0	-10.0	9.0	-17.0	-12.0

VF	Diesel II					VF	Kerosene				
	WSRME	WCME	WSME	HNME	RCME		WSRME	WCME	WSME	HNME	RCME
0	-13.0	-13.0	-13.0	-13.0	-13.0	**0.8**	-16.8	-22.0	1.4	-28.1	-20.4
0.25	-10.4	-12.1	-7.8	-14.3	-12.6	**0.85**	-15.0	-18.0	3.6	-26.4	-18.6
0.5	-8.8	-11.7	-1.2	-15.5	-12.1	**0.9**	-13.2	-15.0	5.4	-22.1	-15.8
0.75	-7.1	-11.1	5.9	-16.9	-10.6	**0.95**	-11.1	-12.4	7.7	-19.6	-13.8
1	-6.0	-10.0	9.0	-17.0	-12.0	**1**	-6.0	-10.0	9.0	-17.0	-12.0

VF	Benzene				
	WSRME	WCME	WSME	HNME	RCME
0.8	-23.1	-27.1	-0.1	-28.6	-26.8
0.85	-19.2	-20.1	0.4	-23.8	-20.4
0.9	-10.8	-15.0	1.8	-21.3	-17.0
0.95	-8.1	-13.5	5.9	-19.0	-15.0
1	-6.0	-10.0	9.0	-17.0	-12.0

Effect of Volume Fraction of Biodiesel on Density of Blends

The approach followed in this analysis was to test the existing equations proposed in the literature to predict the viscosity and densities for fuels which contained biodiesel. Each of the 15 equations, Table 8, predicting the viscosity and density of biodiesel blends was tested for every fuel series, and compared to the experimental values as measured in the Laboratory.

Table 8. Biodiesel correlations to predict the viscosity **and density** of blends

Eq. No.	**Equations**	**References**
1	$\nu = \mathrm{EXP}\left(\mathrm{A} + \mathrm{B.VF} + \frac{\mathrm{C}}{\mathrm{T}}\right)$	[37]
2	$\nu = \mathrm{EXP}\left(\mathrm{A} + \mathrm{B.VF} + \frac{\mathrm{C}}{\mathrm{T}} + \frac{\mathrm{D.VF}}{\mathrm{T}}\right)$	
3	$\nu = \mathrm{EXP}(\mathrm{A.VF} + \mathrm{B.T} + \mathrm{C.VF.T})$	
4	$\nu = \mathrm{EXP}\left(\mathrm{A} + \mathrm{B.VF} + \frac{\mathrm{C}}{\mathrm{T}} + \frac{\mathrm{D.VF}}{\mathrm{T}^2}\right)$	
5	$\nu = \mathrm{EXP}\left(\mathrm{A} + \frac{\mathrm{C}}{\mathrm{T}} + \frac{\mathrm{D.VF}}{\mathrm{T}}\right)$	
6	$\nu = \mathrm{EXP}\left(\mathrm{A} + \frac{\mathrm{C}}{\mathrm{T}} + \frac{\mathrm{D.VF}}{\mathrm{T}^2}\right)$	
7	$\nu = \mathrm{EXP}\left(\mathrm{VF}_1.\ln(\nu_1) + \mathrm{VF}_2.\ln(\nu_2)\right)$	[38]
8	$\nu = \frac{1}{\frac{\mathrm{VF}_1}{\nu_1} + \frac{\mathrm{VF}_2}{\nu_2}}$	
9	$\nu = \left(\mathrm{VF}_1.\nu_1^{1/3} + \mathrm{VF}_2.\nu_2^{1/3}\right)^3$	[38, 39]
10	$\nu = \mathrm{EXP}\left(\mathrm{VF}_1.\ln(\nu_1) + \mathrm{VF}_2.\ln(\nu_2) + \mathrm{VF}_1.\mathrm{VF}_2.\left[\mathrm{A}.\ln\left(\ln\left(\frac{\nu_1}{\nu_2}\right)\right) + \mathrm{B}\right]\right)$	[38]
11	$\nu = \nu_1^{\mathrm{VF}_1}.\nu_2^{\mathrm{VF}_2}\mathrm{EXP}\left(\mathrm{A} + \frac{\mathrm{B}}{\mathrm{T}} + \frac{\mathrm{C}}{\mathrm{T}^2}\right)$	[39]
12	$\nu = \left(\mathrm{VF}_1.\nu_1^{1/3} + \mathrm{VF}_2.\nu_2^{1/3}\right)\mathrm{EXP}\left(\mathrm{A} + \frac{\mathrm{B}}{\mathrm{T}} + \frac{\mathrm{C}}{\mathrm{T}^2}\right)$	
13	$\nu = \mathrm{A} + \mathrm{B.VF}^{\mathrm{C}}$	[40]
14	$\nu = \mathrm{A.EXP}(-\mathrm{B.VF})$	[37]
15	$\nu = \mathrm{EXP}\left(\mathrm{VF}_1.\ln(\nu_1) + (1 - \mathrm{VF}_2).\ln(\nu_2)\right)$	[41]
16	$\nu = \mathrm{A} + \mathrm{B.VF}^{\mathrm{C}} + \mathrm{D.T}^{\mathrm{E}}$	present
17	$\nu = \mathrm{A} + \mathrm{VF}_1(\ln(\nu_{1@313.15℃}) + \mathrm{B}) + \mathrm{VF}_2.\ln(\nu_{2@313.15℃}) + \mathrm{C.T}$	present

The statistical values % AAD was calculated for each biodiesel blend. Thus, each equation under investigation was evaluated for its accuracy for different fuels (total of 5), and each biodiesel (total of 5). As a result, for each of the 12 equations (Eqs. 1 to 12), their standard deviation statistical value of % AAD was calculated. For example, Table 9 shows the ADD% values of WSRME blends three fuels (diesel I, kerosene and Benzene).

Table 9. Evaluation of kinematic viscosity equations (%ADD) for different fuel blends with WSRME

No of Eq.	Diesel I	Kerosene	Benzene
1	0.791	0.547	8.597
2	0.806	0.548	8.609
3	2.105	7.64	12.211
4	0.789	0.485	4.414
5	0.796	3.393	8.599
6	0.794	0.521	4.45
7	0.903	7.303	14.117
8	0.767	7.25	17.708
9	1.125	12.753	29.323
10	0.791	5.209	3.163
11	0.86	4.857	5.942
12	5.776	25.035	57.542
13	0.73	4.651	6.674
14	0.797	3.39	8.59
15	0.903	7.303	14.117

In this study the viscosity of several biodiesel blends with different fuels is measured. Measurements were done at several volume fractions and constant temperature (40℃). Then, according to the above mentioned correlations, some new equations (Eqs (16) and (17)) for kinematic viscosity are presented. These equations, unlike previous correlations in the literature, are independent of biodiesel type, so the kinematic viscosity of every type of fuel−biodiesel blend in each temperature and volume fraction can be predicted using pure properties of fuel and biodiesel (Eq. (17)). Also, the development of proposed correlation (Eq. (16)) was performed by combined two term power models [40]. The results of calculation: the correlation parameters and AAD% values for Eqs (16) and (17) are presented in Table 10. From the table, it is observed that for all biodiesel blends with five different fuels, the predictive Eq. (16) allows the viscosity blends calculation with best results than Eq. (17). This equation can be used for predictive calculation of the viscosity of biodiesel-diesel blend with 0.711-3.313% accuracy on the studied temperature. Eq. (17) correlates satisfactorily the experimental data for biodiesel + diesel fuel systems, AAD being 2.212-3.314%, and unsatisfactorily for biodiesel + kerosene and biodiesel + benzene systems with AAD values between 7.732% and 28.075% for the studied temperature.

The accuracy and validity of the developed equations of the present work as a universal equation are examined also for predicting the kinematic viscosity of any biodiesel-diesel blends. Hence, the experimental data of fuel properties given in literature [42, 40, 37] are used to predict the kinematic viscosity by the developed equations. The ADD% values were calculated to determine the validity of the equations as shown in Table 11. The results prove that the developed equations can reproduce fairly near the experimental information. Moreover, these results of Eq. (16) showed that viscosity prediction of biodiesel-fuel blends can be performed with good accuracy compared to Eq. (17). Therefore, the presented equations have a high accuracy to predict the biodiesel blend properties with diesel fuels.

Table 10. Correlation parameters and %AAD values for Eqs. (16) and (17)

System		`Eq. (16)						Eq. (17)			
		A	B	C	D	E	%ADD	A	B	C	%ADD
Diesel I	**WSRME**	5.094	1.207	1.336	-2.142	-0.047	0.711	16.146	0.910	-0.045	2.212
	WCME	5.138	1.136	1.225	-1.779	-0.010	0.878	16.161	0.863	-0.045	2.525
	WSME	5.673	1.153	1.261	-2.000	0.017	0.886	-13.987	0.865	0.052	2.857
	HNME	0.907	1.169	1.183	2.247	0.026	0.906	-13.957	0.866	0.052	2.129
	RCME	5.583	1.136	1.115	-2.039	0.005	1.000	16.188	0.862	-0.045	3.058
Diesel II	**WSRME**	0.902	1.342	1.632	2.585	-0.023	1.929	-14.119	0.918	0.051	2.712
	WCME	0.466	1.278	1.313	2.351	0.023	1.924	-14.098	0.887	0.051	2.855
	WSME	1.369	1.296	1.371	2.202	-0.035	2.001	-14.095	0.889	0.051	2.924
	HNME	0.403	1.310	1.293	2.370	0.029	2.038	-14.071	0.890	0.051	3.314
	RCME	5.145	1.278	1.184	-2.196	-0.017	1.914	-14.075	0.885	0.051	3.152
Diesel III	**WSRME**	4.706	1.360	1.760	-2.382	-0.041	3.313	-14.253	0.826	0.051	3.349
	WCME	3.068	1.272	1.376	-0.262	0.006	2.494	-14.226	0.776	0.051	2.522
	WSME	0.382	1.291	1.438	2.334	0.007	2.670	-14.225	0.778	0.051	2.599
	HNME	3.652	1.306	1.490	-0.607	0.053	2.856	-14.223	0.779	0.051	2.683
	RCME	1.974	1.268	1.362	0.637	0.044	2.463	-14.227	0.775	0.051	2.488

Kerosene	**WSRME**	1.899	2.920	1.876	-0.576	0.004	4.651	-14.705	1.530	0.049	8.221
	WCME	-2.455	2.718	1.894	3.933	-0.009	4.406	-14.702	1.352	0.049	7.758
	WSME	-3.283	2.744	1.935	4.160	0.017	4.756	-14.703	1.354	0.049	7.876
	HNME	-4.104	2.764	1.967	4.325	0.039	4.993	-14.703	1.356	0.049	7.951
	RCME	4.790	2.712	1.884	-3.696	-0.009	4.332	-14.702	1.351	0.049	7.732
Benzene	**WSRME**	4.307	3.678	2.753	-6.074	-0.090	6.578	-14.753	1.226	0.049	28.066
	WCME	-4.198	3.416	3.084	4.887	0.000	8.316	-14.734	0.924	0.049	27.697
	WSME	-0.610	3.454	3.145	1.025	0.043	8.705	-14.736	0.927	0.049	27.911
	HNME	-3.604	3.484	3.193	5.236	-0.034	9.086	-14.738	0.928	0.049	28.075
	RCME	-0.933	3.406	3.069	1.447	0.020	8.181	-14.734	0.928	0.049	27.691

CONCLUSIONS

An experimental investigation has been conducted in this work to examine the properties of five biodiesel blends with different commercial fuel. In this study, five biodiesel was produced from vegetable oils and waste vegetable oil and blended with three various diesel fuels by different percentage of biodiesel. In addition, the effects of biodiesel-kerosene and biodiesel-benzene mixture as an alternative fuel on properties of fuel were experimentally investigated. Experimental viscosity and densities data for blends of biodiesel with five different fuels were reported. Also, the cold flow properties in term of cloud point and pour point for biodiesel blends were presented.

Table 11. ADD% for empirical correlations developed in this work to predict the kinematic viscosity of biodiesel blends

Reference	System	Eq. No.	Temperature	A	B	C	D	E	%ADD
[42]	**Rapeseed + Diesel**	**16**	293.15	4.552	2.518	2.023	1.014	-0.044	0.198
			298.15	4.894	2.242	1.986	-0.052	0.133	2.936
			303.15	3.581	1.812	1.49	0.678	-0.014	0.232
			313.15	3.544	1.071	1.541	0.06	-0.176	0.274
			323.15	2.679	1.485	0.945	-0.075	-0.09	8.388
	Rapeseed + Diesel	**17**	293.15	-13.593	2.237	0.059	-	-	3.105
			298.15	17.017	1.951	-0.046	-	-	4.229
			303.15	-14.056	1.581	0.055	-	-	2.670
			313.15	-14.341	0.82	0.053	-	-	2.116
			323.15	16.128	1.196	-0.046	-	-	8.065
	Rapeseed + Benzene	**16**	293.15	1.779	6.449	3.22	-0.54	0.049	8.649
			298.15	-0.567	5.746	3.128	3.072	-0.124	6.845
			303.15	-2.548	4.977	2.985	1.705	0.122	7.011
			313.15	0.99	3.698	2.712	-0.464	-0.144	6.440
			323.15	0.633	3.052	1.921	-0.244	-0.231	5.182
	Rapeseed + Benzene	**17**	293.15	-15.288	3.784	0.053	-	-	33.889
			298.15	-15.266	3.172	0.052	-	-	34.965
			303.15	-15.217	2.534	0.052	-	-	30.710
			313.15	-15.127	1.437	0.05	-	-	23.938
			323.15	-15.108	0.984	0.049	-	-	20.196
[40]	**Corn +Diesel**	**16**	283.15	4.414	3.758	0.862	-0.453	-0.177	0.379
			293.15	2.064	2.846	0.78	2.073	-0.106	0.555
			303.15	2.687	2.297	0.689	0.204	-0.034	0.495
			313.15	2.772	1.428	0.47	-0.091	0	0.803
	Corn +Diesel	**17**	283.15	0	3.293	0.012	-	-	0.994
			293.15	0	2.356	0.008	-	-	5.691
			303.15	0	1.775	0.007	-	-	2.658
			313.15	0	0.826	0.006	-	-	4.659
	Hazelnut +Diesel	**16**	283.15	4.322	3.099	0.66	-0.123	0.002	1.105
			293.15	7.404	3.074	0.616	-5.116	-0.032	1.950
			303.15	-0.034	2.975	0.691	3.737	-0.048	1.799
			313.15	2.057	1.583	0.533	0.567	0.008	2.014
	Hazelnut +Diesel	**17**	283.15	0	2.506	0.012	-	-	3.780
			293.15	0	2.436	0.009	-	-	4.859
			303.15	0	2.412	0.007	-	-	3.758
			313.15	0	0.992	0.006	-	-	4.345

[37]	**Peanut and sunflower + Ultra low sulfur diesel**	**16**	293.15	5.026	7.928	1.42	-0.528	0.045	1.529
			303.15	3.329	5.677	1.394	0.197	-0.123	1.333
			313.15	5.369	4.238	1.349	-6.253	-0.152	1.495
			323.15	2.277	3.207	1.308	0.292	-0.592	1.524
			333.15	1.945	2.518	1.308	1.936	-2.055	0.979
			343.15	1.695	2.039	1.286	-0.026	-0.074	0.919
			353.15	1.446	1.661	1.258	0.084	-0.233	0.838
			363.15	0.966	1.403	1.235	0.529	-0.086	1.117
			373.15	0.471	1.182	1.312	0.528	0.046	0.896
	Peanut and sunflower + Ultra low sulfur diesel	**17**	293.15	26.488	6.928	-0.08	-	-	4.498
			303.15	26.091	4.689	-0.079	-	-	4.205
			313.15	25.8	3.26	-0.077	-	-	3.560
			323.15	25.591	2.233	-0.076	-	-	6.064
			333.15	25.435	1.543	-0.074	-	-	4.492
			343.15	25.313	1.065	-0.072	-	-	2.632
			353.15	25.217	0.688	-0.072	-	-	3.585
			363.15	25.132	0.429	-0.068	-	-	11.379
			373.15	25.071	0.206	-0.067	-	-	5.400

In the present study, 15 equations predicting the viscosity of biodiesel mixtures were examined. New equations are obtained for estimating kinematic viscosity of the blends. The difference of these correlations with the previous ones is that constants of these equations are independent of the used biodiesel and diesel type. On the basis of observed fuel properties for all biodiesel blended fuels with five different fuels, the following conclusion may be drawn:

- Results showed that by increasing the volume fraction of biodiesel, kinematic viscosity and density of blend are increased. Fuel kinematic viscosity and density decrease linearly with the increase in volume fraction of biodiesel for a particular fuel.
- From this study, it is understood that the additives (kerosene and benzene) play an extremely important role to increase cold flow properties and reduce the kinematic viscosity of biodiesel.
- The low temperature properties of biodiesel fuels are less favorable than diesel fuel. However, blending with additives like kerosene, benzene and cold flow improver additives improves the cold flow performance of biodiesel.
- Biodiesel is mixed with kerosene and benzene to bring many of the beneficial characteristics to be a substituted diesel fuel.
- Kerosene and benzene can play a role as a diluent agent to reduce the characteristic of cold flow properties of biodiesel.
- The use of a mixture of biodiesel- kerosene and biodiesel -benzene as a substituted diesel fuel depends on its characteristics fuel properties, which is to meet the specification requirement of diesel fuel.
- Kerosene and benzene can be utilized as blending component with biodiesel to be a substituted diesel fuel.
- This study develops two empirical correlations to predict the kinematic viscosity of biodiesel blends. The developed equations were fitted using experimental information gathered from the literature.
- Eq. (16) gives the best qualitative and quantitative estimates in compared to other type mixing models often suggested in literature for predicting the changes of kinematic viscosities of biodiesel-fuel blends with respect to blending fraction.

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