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Original Research Article

Determination of some fuel properties of binary biodiesel and binary biodiesel – diesel blend fuels obtained from camelina oil and waste frying oils

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ABSTRACT

In today's studies on liquid biofuels, it is observed that many of them focus on blends of single biodiesel with diesel. These studies have shown that biodiesel produced from different feedstocks exhibits similar properties to traditional diesel fuel in terms of fuel characteristics and engine performance, indicating the potential of biodiesel to replace diesel fuel. However, recent research has shown limited studies involving the blending of dual biodiesel with traditional diesel fuel.

In this study, high oil content camelina plant, which has an important place in ensuring sustainability in human food production, in other words, it is not suitable for human food and has the potential to significantly increase our domestic biofuel production, and domestic waste frying oil, which significantly reduces the cost of biodiesel raw material production, were selected as biodiesel feedstock. Binary biodiesel fuels ($D_0C_{50}WF_{50}$, $D_0C_{75}WF_{25}$, and $D_0C_{25}WF_{75}$) were obtained by mixing the biodiesel fuels produced from camelina and domestic waste frying oil by transesterification method in the ratio of 1:1 and 1:3 by volume. Binary biodiesel-diesel blend fuels were obtained by blending binary biodiesel fuels ($D_{75}C_{12.5}WF_{12.5}$, $D_{50}C_{25}WF_{25}$ and $D_{25}C_{37.5}WF_{37.5}$) with conventional diesel fuel (diesel) after blending at 1:1 ratio by volume. As a result of the research, the physicochemical properties (density, kinematic viscosity, flash point, water content, calorific value, cold filter plugging point, cloud and pour point, copper strip corrosion) of the prepared binary biodiesel and binary biodiesel+diesel blend fuels were determined. The results of the analyses of the blend fuels were determined in accordance with the relevant biodiesel standards (EN 14214, ASTM D-6751) and the results were also compared with the reference fuel, diesel fuel.

Keywords: waste frying oil, camelina oil, dual biodiesel, fuel properties.

1. Introduction

In recent years, there has been an increased interest in research on alternative and renewable energy sources due to the parallel increase in the world's population, the growing demand for energy, the decreasing reserves of fossil fuels, and the negative effects of these fuels, particularly on human health and the environment, as a result of the increase in carbon dioxide levels in the atmosphere through combustion s [1–2].

All fuels that can be used in internal combustion engines as alternatives to fossil fuels (such as gasoline, diesel, etc.) and are produced from renewable energy sources belong to the category of biofuels. Biofuels are renewable, have an essentially unlimited source, and are environmentally friendly products that can be used in internal combustion engines without requiring any modifications. Biodiesel is a type of biofuel that can be produced from various biological sources and is considered an equivalent to diesel fuel. From a technical standpoint, biodiesel is defined as a mono-alkyl ester obtained by reacting vegetable, animal, or waste oils with simpler alcohols such as methanol and ethanol in the presence of a catalyst [3]. Biodiesel has been proven to be a viable alternative due to its comparable performance to diesel and its ability to reduce greenhouse gas emissions [4].

Camelina has many favorable agricultural and economic characteristics that have the potential to significantly increase domestic biofuel production. In recent years, camelina has gained attention as an oilseed crop due to its high oil yield per hectare, high seed oil content, exceptional level of α-linolenic acid in its oil, and its potential as a low-input biofuel source. In today's world, especially to ensure sustainability in food production, it is essential that oilseed crops used for biofuel production are sourced from non-food resources. In this context, camelina, which has a high oil content, is currently suitable for biofuels, and is not suitable for human consumption, meets this condition [5].

Camelina is cultivated as a feedstock for biofuel production in certain northern states of the United States. Research has indicated that when camelina is cultivated on a large scale as a biodiesel feedstock, it has a low potential for becoming an invasive weed. Additionally, the oil extracted from camelina serves as a valuable input for biodiesel production through transesterification. Furthermore, it has been demonstrated that it can also be used as a renewable jet fuel through hydrodeoxygenation/hydrocracking processes [6].

Since the American Society for Testing and Materials (ASTM) has approved the technical properties of camelina biocarosene, it has a privileged position as the preferred renewable fuel for airline companies [7]. In the United States, various companies such as Accelergy Corp., Altair, Inc., Biojet Corp., and Sustainable Oils LLC have successfully produced camelina-derived jet fuels. It has been found that camelina-based biokerosene used in aviation leads to a significant reduction of approximately 84% in greenhouse gas emissions compared to petroleum kerosene [7].

The high production cost of biodiesel presents a significant obstacle to its commercialization. The cost of raw materials used in biodiesel production also plays a crucial role in determining this cost. Therefore, in order to promote the use of biodiesel produced from different feedstocks, it is essential to minimize the raw material cost, which often constitutes a high proportion of the production cost. For these reasons, waste cooking oils, waste animal fats, soap residues, yellow and brown greases have recently been preferred as raw materials for biodiesel production to minimize the cost of biodiesel feedstock [8]. In order to efficiently utilize waste frying oils in biodiesel production, it is necessary for the oil to be separated as waste oil in a timely manner. Currently, regulations regarding the control of vegetable waste oils stipulate that waste oils should be collected, temporarily stored, recovered, or disposed of in accordance with these regulations. According to existing regulations, due to some adverse effects of waste oils (such as impacts on human health, water pollution, air pollution, clogging of sewage lines, etc.), the only approved method for waste oil disposal is conversion into biodiesel [9]. In this context, the preference for waste oils in biodiesel production not only reduces fuel costs but also mitigates potential adverse environmental effects [10].

2. Literature Review

In today's research on liquid biofuels, a significant focus has been on the blends of single biodiesel with diesel. These studies have shown that single biodiesel has the potential to be a candidate for replacing traditional diesel fuel, as it exhibits physicochemical properties very similar to those of conventional diesel fuel. Upon examining recent research, it becomes evident that there have been limited and scarce studies specifically focused on the direct impact of blending two different biodiesels with diesel fuel on the physicochemical properties of these biodiesels [11-12].

In their study, R. Kumar and Singh [4] examined the effects of binary biodiesel-diesel blend fuels derived from Mexicana Argemone and Mahua oils on the performance parameters and emission characteristics in a single-cylinder, four-stroke diesel engine. As a result of the study, the researchers found that for the D60A20M20 fuel blend (60% diesel, 20% Argemone, and 20% Mahua) among the diesel and binary biodiesel blends, there was a slight increase in brake power and specific fuel consumption (an average of 0.06 kg/kWh) for biodiesel blends at full load compared to diesel fuel. Additionally, they noted that carbon monoxide (CO) and hydrocarbon (HC) emissions decreased for this biodiesel blend compared to diesel fuel, while NOx emissions were higher.

Saravanan et all. [13] investigated the effects of blending binary biodiesel blends of equal volume (1:1) prepared from rapeseed (RA) and mahua (MU) with varying proportions of diesel fuel (BL20, BL40, BL60 and BL80) on the performance and emission values in a diesel engine. They found that the BL20 fuel, a binary biodiesel blend consisting of 20% RM and 80% diesel, provided performance values closer to diesel fuel. Furthermore, they noted that compared to diesel, this same fuel blend exhibited a 20.66% reduction in CO emissions, an 8.56% reduction in HC emissions, a 6.9% reduction in smoke opacity, and a 3.77% increase in NOx emissions. As a result of their research, the authors emphasized that the BL20 blend could be used as an alternative fuel to diesel without any modifications to the engine.

Nalgundwar et all. [14] conducted a study where they prepared binary biodiesel blends composed of two different types of biodiesels, palm (Elaeis guineensis) and jatropha (Jatropha curcas), and blended them with diesel fuel at various ratios. They determined the physicochemical properties of the blended fuels and then tested them in a single-cylinder diesel engine to evaluate their motor performance and emissions in comparison to diesel fuel. The study revealed that when compared to diesel, the D90PB5JB5 fuel blend (90% diesel and 10% biodiesel) exhibited an average 4.65% increase in brake power, while the fuel D20JB40PB40 (20% diesel and 80% biodiesel) containing a higher proportion of biodiesel showed up to a 15% increase in brake thermal efficiency. Additionally, the study indicated that the fuels D90JB5PB5, D80JB10PB10, and D70JB15PB15 (biodiesel blends containing 10%, 20%, and 30% biodiesel) resulted in average reductions of 7.1%, 17.7%, and 14.5% in CO emissions, respectively. On the other hand, fuels D90JB5PB5 and D80JB10PB10 showed average increases of 5.3% and 9.2% in NOx emissions, respectively, when compared to diesel.

In our study, camelina and waste frying oils, which have no edible value, were used in order to minimize the cost of raw materials, which constitute a large part of the production cost. In order to eliminate the problems that may occur in the supply of raw materials, it is aimed to examine the change in the properties of the fuels obtained by blending two different biodiesels and mixing them with diesel. In our study, binary biodiesel fuels obtained from camelina and waste frying oils were blended with diesel fuel (motor diesel) at a 1:1 volume ratio to create binary biodiesel-diesel blends. Additionally, binary biodiesel fuels were prepared by blending biodiesel fuels with each other at volume ratios of 1:1 and 1:3. As a result of the research, the physicochemical properties of binary biodiesel and binary biodiesel-diesel blends were determined, and an attempt was made to assess the conformity of the analysis results with relevant biodiesel standards (EN 14214, ASTM D-6751).

3. Materials and Methods

3.1. Materials

In the present study, Arslanbey variety camelina seeds, used for the production of camelina biodiesel were obtained from the Republic of Türkiye Ministry of Agriculture and Forestry Field Crops Central Research Institute. The oil extraction process from camelina seeds was conducted in three distinct stages. The seeds were first pre-treated in the crushing machine and then heated and tempered and cold pressed in a 200-ton hydraulic press to obtain oil and meal (Figure 1).

The waste frying oil used in the study was obtained by using sunflower oil as domestic frying oil.

Euro diesel, which has a dual use as reference fuel and blended fuels, was obtained from the market.

Figure 1. Camelina Seed (Arslanbey Variety).

3.2. Methods

3.2.1. Filtration of camelina and waste frying oils

Crude camelina oil and waste frying oil were subjected to filtration before being used in biodiesel production. The conditions of the oils before and after the filtration process and the filtration process applied to the oils are shown in Figure 2.

Figure 2. Filtration process applied to raw camelina and waste frying oils.

3.2.2. Stages of Biodiesel Production from Camelina and Waste Frying Oils

Following the filtration processes of both oils, biodiesel production was carried out for camelina oil (referred to as C_{100}) and waste frying oil (referred to asWF_{100}). The biodiesel production processes involved six stages through the transesterification method, including the mixing of alcohol and catalyst, esterification reaction, phase separation, washing with distilled water, drying, and obtaining methyl ester (biodiesel) as depicted in Figure 3. To separate glycerin components in the oils of different feedstocks during biodiesel production, methyl alcohol was used, and sodium hydroxide (NaOH) was employed as a catalyst to break down triglycerides [2].

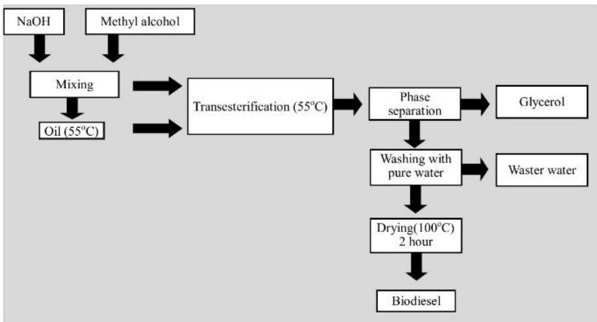

Figure 3. Stages of Biodiesel Production [15-1].

In the biodiesel production process, a total of 20% by volume of methyl alcohol (CH3OH) and 3.5 g of sodium hydroxide (NaOH) per liter of oil were used as a catalyst for the esterification reaction. To produce methoxide for biodiesel production, methyl alcohol and sodium hydroxide were mixed in an appropriate container until dissolved, and this mixture was added to the heated raw oil at 55 ºC using a magnetic stirrer with thermostat control. The resulting mixture was stirred for 90 minutes at a reaction temperature of 55 ºC. After the mixing process, it was allowed to settle for the separation of glycerol from the oil (phase separation). Subsequently, the glycerol was separated from the oil. Following this step, the temperature of the biodiesel was raised to 75ºC to remove any remaining methyl alcohol (CH3OH) in the raw biodiesel.

During biodiesel production, washing with distilled water was carried out to remove the unreacted alcohol, remaining fatty acids, catalyst material and glycerol that may remain during the phase separation phase. The washing process was carried out using 20% distilled water. After the completion of the washing process, the water used in the washing process was allowed to settle and the settled waste water was separated from the crude biodiesel. The precipitated water was removed and the crude biodiesel was subjected to drying at 100ºC in a magnetic mixer with a probe heater and the water was removed [16-1-2].

The biodiesel production stages described above were applied to both camelina and waste frying oils, resulting in the successful production of biodiesel from both sources. The production stages of Camelina biodiesel, produced using the transesterification method, are outlined in Figure 4. The same stages were also applied in the production of waste frying oil biodiesel.

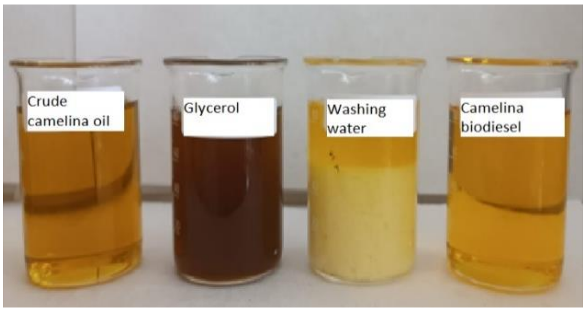

Figure 4. Stages of Camelina Biodiesel Production Using the Transesterification Method.

Table 2. Prepared Fuels and Percentage Blend Ratios

Fuels	D (%)	C (%)	WF (%)
D_{100}	100	-	-
C_{100}	-	100	-
WF_{100}	-	-	100
$D_{75}C_{12.5}WF_{12.5}$	75	12.5	12.5
$D_{50}C_{25}WF_{25}$	75	25	25
$D_{25}C_{37.5}WF_{37.5}$	75	37.5	37.5
$D_0C_{75}WF_{25}$	-	75	25
$D_0C_{50}WF_{50}$	-	50	50
$D_0C_{25}WF_{75}$	-	25	75

3.3. Preparation of blend fuels

To comprehend the impact of binary biodiesel blends, a substantial amount of biodiesel is used in blending [11-14]. For this purpose, high biodiesel blends were preferred in the blending with diesel to determine their effect on fuel properties. Blend fuels were prepared by mixing predetermined volumes of biodiesel and diesel using a homogenizer.

To determine the fuel properties, the percentage blend ratios of the prepared fuels and blends are presented in Table 1, and the overall appearances of these fuels are depicted in Figure 5. For ease of use, diesel is symbolized as "D," camelina biodiesel as "C," and waste frying oil biodiesel as "WF." The numbers added as subscripts below the symbols represent the blend ratios of the fuels.

Figure 5. Prepared Biodiesels and Fuel Blends

3.4. Determination of Physicochemical Properties of Fuels and Blends

In this study, the physicochemical properties of all fuels and blends (kinematic viscosity, density, calorific value, water content, flash point, cloud point, cold filter plugging point, pour point, copper strip corrosion) were determined. These determinations were carried out at the fuel analysis laboratory established within the Department of Agricultural Machinery and Technologies Engineering at Selcuk University, as part of the project numbered DPT 2004/7 [17], utilizing the measurement devices available in the laboratory (Figure 6).

Figure 6. Fuel Analysis Laboratory

Analyses of the fuels and blends were conducted in accordance with the operating procedures of the measurement instruments, as outlined in Table 2. The conformity of the analysis results with the standards currently applied for biodiesel, namely the European Union EN 14214 and the American ASTM D 6751 standards, was determined (Table 3).

4. Results and Discussion

The density, kinematic viscosity, flash point, calorific value, CFPP, water content, pour point, and cloud point values of diesel, camelina biodiesel, waste oil biodiesel, and blend fuels are presented in Figure 7. The results have been compared with TS EN 14214 and ASTM D 6751 standards.

The density values for C_{100}, WF_{100}, and binary biodiesel fuel blends were found to be very close to each other.

Table 3. Specifications of Testing Instruments and Measurement Standards

Fuel Property	Devices	Measurement Range	Unit	Measurement Accuracy	Manufacturer	Standard
Density	Kem Kyoto DA-130N	0.0000 - 2.0000	g cm^{-3}	±0.0001	Kem Kyoto Electronics, Japan	EN ISO 3675 EN ISO 12185
Kinematic viscosity	Koehler K23377	Ambient temperature – 150	ºC	±0.01	Koehler Instrument Company, US	EN ISO 3104
Flash point	Koehler K16270	Ambient temperature - 370	ºC	±0.01	Koehler Instrument Company, USA	EN ISO 2719 EN ISO 3679
Water content	Kem Kyoto MKC-501	10µg-100mg	µg	±0.01	Kem Kyoto Electronics, Japan	EN ISO 12937
Calorimeter	IKA C 200	0-40.000	J	±0.0001	IKA, UK	DIN 51900
Cold filter plugging point	Tanaka AFP-102	With a coolant down to -60°C	°C	±0.01	Tanaka Scientific Limited, Japan	ASTMD6379
Cloud and pour point	Koehler	-	°C	-	-	ASTM D97
Copper strip corrosion	Koehler K 25330	0-190	°C	±0.01	Koehler Instrument Company, USA	EN ISO 2160

Table 4. Biodiesel Standards

Property	Unit	European Standards		American Standards	
		EN 14214	Test Method	ASTM D 6751	Test Method
Density (at 15°C)	(g cm^{-3})	0.86-0.90	EN ISO 3675 EN ISO 12185	-	-
Kinematic Viscosity (at 40°C)	(mm^2 s^{-1})	3.5-5.0	EN ISO 3675 EN ISO 12185	1.9-6.0	D 445
Flash Point	(°C)	≥120	EN ISO 3104 ISO 3105	≥130	D93
Sulfur Content	(mg kg^{-1})	≤10	EN ISO 3679	≤15	D 5453
Sulfated Ash	% (mol mol^{-1})	≤0.02	EN ISO 20846 EN ISO 20884	≤0.02	D 874
Water Content	(mg kg^{-1})	≤500	ISO 3987	≤500	D 2709
Carbon Residue (% at 10% distillation residue)	% (mol mol^{-1})	≤0.3	EN ISO 12937	≤0.5	D 4530
Copper Strip Corrosion (3h/50°C)	-	Class 1	EN ISO10370	≤3	D 130
Cetane Number		≥51	EN 14112	≥-47	D 613
Acid Number	mgKOH kg^{-1}	≤0.5	EN ISO 5165	≤0.5	D 664
Total Glycerol	% (mol mol^{-1})	≤0.25	EN 14105	≤0.24	D 6584
Phosphorus Content	(mg kg^{-1})	≤10.0	EN 14105	≤10.0	D 4951
Cold Filter Plugging Point	(°C)	-	EN 14107	-	-
Pour Point	(°C)	-	EN 116 ISO 3016	-	-

In the case of ternary fuel blends, the increase in the volume of diesel decreased the density values of the fuel blends. Similar results have been reported by Eryılmaz et al. [1], Sirviö et all. [18] and Yang et all. [19]. The viscosity of the fuel significantly affects the fuel delivery system. High-viscosity fuels can lead to decreased combustion quality, weak atomization, clogging of fuel injectors, and increased carbon deposits in piston ring zones [20]. In this study, the kinematic viscosity values of WF_{100} biodiesel and the binary blend biodiesel $D_0C_{25}WF_{75}$ exceeded the limit specified in the EN 14214 standard. However, according to ASTM D 6751 standard, all biodiesel fuels and blends fell within the acceptable range for kinematic viscosity values.

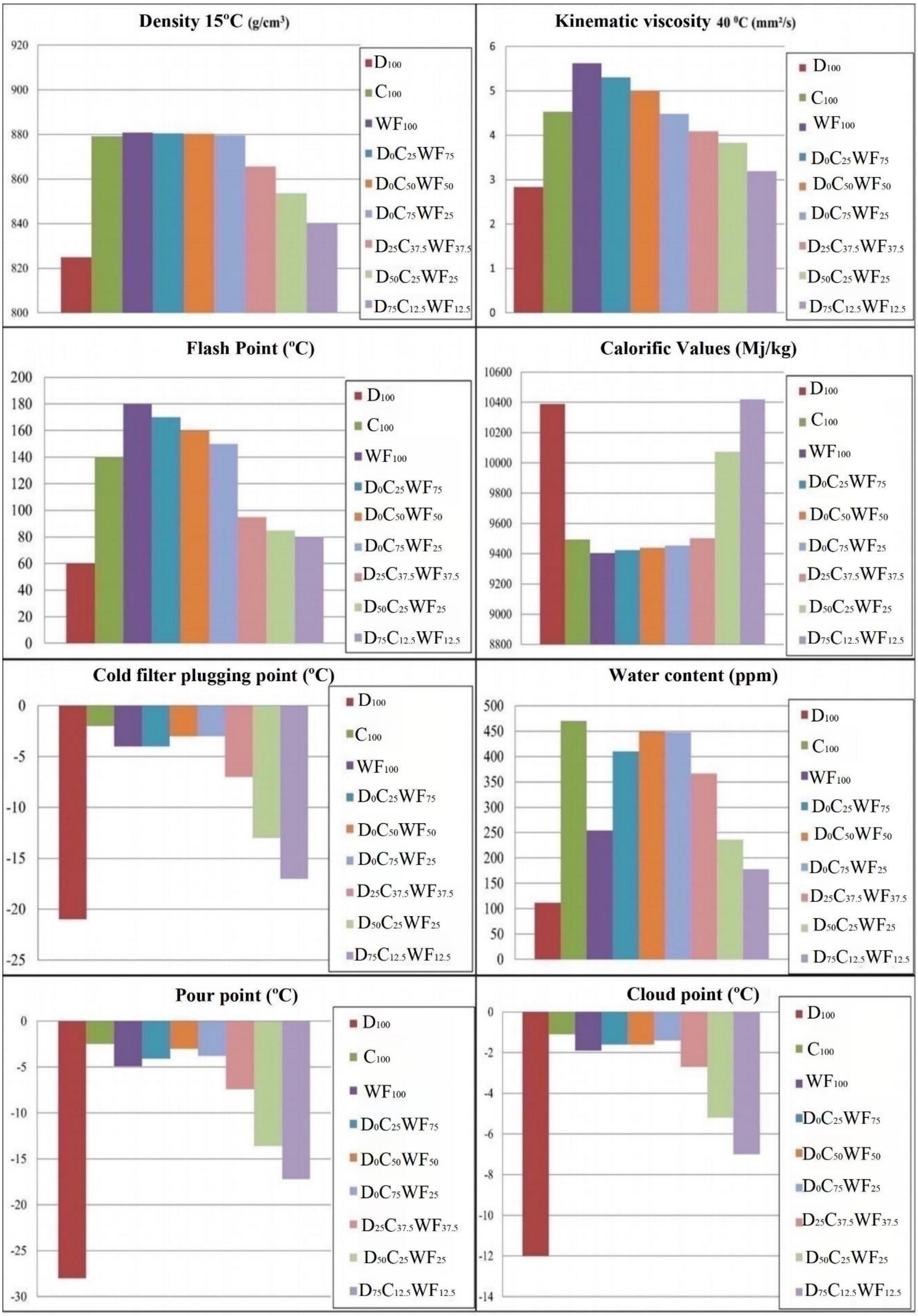

Figure 7. Fuel properties of diesel, camelina biodiesel, waste cooking oil biodiesel, binary biodiesel, and binary biodiesel+diesel blends.

Increasing the volume of camelina biodiesel in binary biodiesel blends ensured that the kinematic viscosity value remained within the specified limits. The kinematic viscosity values for $D_0C_{75}WF_{25}$, $D_0C_{50}WF_{50}$, and $D_0C_{25}WF_{75}$ binary fuel blends were obtained as 4.48-4.99 and 5.2 mm² s^{-1}, respectively. In other words, an increase in the volume of waste frying oil in binary blends increased the kinematic viscosity value. Similar variations were observed in binary biodiesel+diesel fuel blends prepared with the same volume ratios. An increase in diesel content in these fuels and a decrease in the volume of camelina and waste frying biodiesel reduced the viscosity values of the fuel blends. This can be attributed to the water mixing into waste frying oil and exposure to heat, which increases the amount of free fatty acids, viscosity, hydrolysis rate, density, and saponification value of triglycerides [21].

Flash point is expressed as the lowest temperature value required for the combustion of the air with the fuel vapour accumulated on the fuel after it is heated. High flash point is considered suitable for storage and transport. The flash point of waste cooking oil biodiesel was higher than D_{100}, C_{100} and blended fuels. In binary fuel blends, the increase in the volume of waste frying biodiesel increased the flash point. Şener (22) reported in his study that decreasing the volume of waste oil biodiesel in its mixture with diesel fuel reduces the flash point. As a ternary blends, the increase in diesel by volume and the decrease in camelina and waste frying biodiesel decreased the flash point. The presence of monoglycerides in waste frying oil caused the fuel blends to have a high flash point [23-24].

The amount of energy is expressed as the calorific value released during the combustion of a fuel. An increase in the calorific value indicates an increase in the chain length of saturated hydrocarbons. An increase in unsaturation (a decrease in hydrogen content) significantly reduces the calorific value. An increase in oxygen content reduces the calorific value of biodiesel fuel compared to traditional petroleum-based diesel fuel. The calorific values of C_{100} and WF_{100} fuels are 8.63% and 9.48% lower than diesel fuel, respectively. Maliyekkal and Shaija [25] reported that different biodiesel samples, including waste cooking oil biodiesel, have lower calorific values compared to diesel fuel due to the higher oxygen content in biodiesel. The calorific values of binary fuel blends $D_0C_{25}WF_{75}$, $D_0C_{50}WF_{50}$, and $D_0C_{75}WF_{25}$ are 9424, 9438, and 9455 MJ kg^{-1}, respectively. The calorific values of binary fuel blends are close to each other. In ternary fuel blends, the increase in diesel by volume and decrease in biodiesel ratios in the fuel increased the calorific value. The reason for this can be attributed to the decrease in the oxygen content of the fuels with the decrease in the biodiesel ratio in the blend fuels and the increase in the calorific value accordingly.

The Cold Filter Plugging Point (CFPP) is considered an important parameter that measures the usability of fuels, including biodiesel, at low temperatures. CFPP determines the temperature at which wax crystals begin to form in the fuel, potentially causing engine malfunctions by clogging fuel lines and filters [26]. Therefore, CFPP is a crucial cold flow property used to evaluate the performance of fuels at low temperatures [27]. In this study, the CFPP of diesel fuel was -21°C, while camelina and waste cooking oil biodiesel had CFPP values of -2°C and -4°C, respectively. Leng et all. [28] reported that biodiesel has a high pour point, cloud point, and CFPP, indicating a tendency to crystallize under low-temperature conditions. The CFPP of biodiesel is also influenced by its fatty acid composition. Studies have shown that biodiesels with different fatty acid contents have different CFPP values [29]. Biodiesel's oxidation stability is another factor that can lead to residue formation and increase CFPP [27]. In binary fuel blends, an increase in the volume of waste cooking oil biodiesel has reduced the Cold Filter Plugging Point. This can be attributed to the higher content of saturated fatty acids in waste cooking oil biodiesel. Saturated fatty acids have a higher melting point and tend to solidify at lower temperatures, resulting in poor cold flow properties [28]. In the triple fuel blends, the decrease in biodiesel by volume and the increase in the amount of diesel decreased the CFPP.

Cloud point and pour point are also considered within the scope of cold flow properties of fuels. The temperature at which wax crystals begin to form in the fuel as the ambient temperature decreases is referred to as the "cloud point." Additionally, the lowest temperature at which the fuel loses its flowability is called the "pour point" [30]. Camelina and waste cooking oil biodiesels have been found to have higher pour and cloud points compared to diesel fuel. Generally, biodiesel fuels have higher pour and cloud points compared to diesel fuels [1-18-19]. This is because biodiesel is derived from vegetable oils, which have higher viscosity and solidification temperatures than petroleum-based diesel fuel [31]. The higher viscosity of biodiesel leads to an increase in pour and cloud points, making the fuel more prone to gelling and clogging fuel filters in cold weather conditions [32]. The pour and cloud points of fuel blends exhibit similar characteristics to those of cold filter plugging points.

The water contents of D_{100}, C_{100}, WF_{100} and fuel blends were found to be within EN14214 and ASTM D 6751 standards. The water content of camelina biodiesel was 84% higher than that of waste cooking oil biodiesel. Waste cooking oil biodiesel is produced from used cooking oil that has already undergone a cooking process. During this process, the water contained in the oil is evaporated, resulting in a lower water content in the waste cooking oil [24]. The water content can vary depending on the production process and the source of the feedstock. In binary fuel blends, the increase of camelina biodiesel by volume and the decrease of waste cooking oil biodiesel increased the water content of the fuel blends. In ternary fuel blends, the water content of the fuel blends decreased with the increase of diesel fuel by volume and the decrease of biodiesel fuel ratio. High water content in biodiesel can lead to problems such as water accumulation and microbial growth in fuel tanks and transport equipment [33].

5. Conclusions

In this study, the quality and relationships of biodiesel produced from raw camelina oil (C_{100}), waste cooking oil (WF_{100}), binary biodiesel blends ($D_0C_{25}WF_{75}$, $D_0C_{50}WF_{50}$, $D_0C_{75}WF_{25}$), and ternary fuel blends ($D_{25}C_{37.5}WF_{37.5}$, $D_{50}C_{25}WF_{25}$, $D_{75}C_{12.5}WF_{12.5}$) were investigated.

The physicochemical properties of the fuel samples (C_{100}, WF_{100}, $D_0C_{25}WF_{75}$, $D_0C_{50}WF_{50}$, $D_0C_{75}WF_{25}$, $D_{25}C_{37.5}WF_{37.5}$, $D_{50}C_{25}WF_{25}$, $D_{75}C_{12.5}WF_{12.5}$) were as follows, respectively: density (g cm^{-3}) (at 15 °C) 879.2; 880.3; 880.4; 880.3; 879.6; 865.7; 853.7; and 840.3, kinematic viscosity (mm^2 s^{-1}) (at 40 °C) 4.53; 5.62; 5.3; 4.99; 4.48; 4.09; 3.83; 3.19, flash point (°C) 140; 180; 170; 160; 150; 95; 85; 80, calorific value (Mj kg^{-1}) 9494; 9405; 9424; 9438; 9455; 9502; 10073; 10420, cold filter plugging point (°C) -2; -4; -4; -3; -3; -7; -13; -17, water content (ppm) 470.18; 254.51; 410.6; 448.76; 447.8; 366.5; 236.2; 178.1, pour point (°C) -2.5; -4.9; -4.1; -3; -3.8; -7.4; -13.6; -17.2, cloud point (°C) -1.1; -1.9; -1.6; -1.6; -1.4; -2.7; -5.2; -7, and copper strip corrosion (3h at 50°C) was determined as 1a for all fuels. It was observed that waste cooking oil biodiesel (WF_{100}) and the binary biodiesel blend $D_0C_{25}WF_{75}$ did not comply with the EN 14214 standard in terms of kinematic viscosity values. Camelina biodiesel (C_{100}) and the binary biodiesel blends $D_0C_{50}WF_{50}$ and $D_0C_{75}WF_{25}$ were found to conform to EN 14214 standards. The ternary fuel blend $D_{75}C_{12.5}WF_{12.5}$ achieved values closest to diesel fuel quality. According to these results, it was determined that waste cooking oil biodiesel can be made suitable for direct use in engines by blending it with binary or ternary fuel blends.

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