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Research Article

MIXING OF BIODIESELS PRODUCED FROM DIFFERENT SOURCES WITH JET FUEL AND COMPARISON OF FUEL PROPERTIES OF THE BLENDS

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Air quality standards set forth by the Clean Air Act and its amendments have established guidelines for the reduction of harmful ground-level emissions from the aviation sector. The aviation industry raises environmental concerns as it is vulnerable in the event of an energy crisis and also consumes fossil fuels. In this sector, when using biomass based fuels instead of fossil fuels, possible energy crises will be prevented and greenhouse gas emissions will also be reduced. This is a kind of biomass energy (bioenergy), biodiesel, can be used in diesel engines as an alternative fuel. Biodiesel is produced from renewable resources such as vegetable and animal fats. Biodiesel is sustainable, environmentally friendly, non-toxic, an alternative fuel for diesel engines. In this study, biodiesel fuels were produced from different feedstocks (canola oil, algae oil, sunflower oil, cottonseed oil, and waste cooking oil) and then blended with jet fuel (JP-8) at various ratios including 5-10-15-20% (on volume basis, v/v). The some critical fuel properties of the blends were compared with each other and those of the jet fuel. Considering the properties of the biodiesel used, it is seen that the fuel with the highest density, viscosity, flash point and freezing point was waste cooking oil (WCO) (892 kg/m^3, 4.66 mm/s^2, 180 ^{o}C, -8 ^{o}C). Accordingly, WCO biodiesel blends were found to be higher than others. In addition, it was determined that the algae biodiesel used in the study had the best density (881 kg/m^3), flash point (150 ^{o}C) and freezing point (-14 ^{o}C), and cotton biodiesel met the most suitable viscosity value.

Key words*: Jet fuel, biodiesel, blend, fuel properties*

1. Introduction

Energy, which is of primary importance in ensuring the development, and welfare of countries, has recently become one of the most strategic tools in the international system. Energy policies address issues such as the safe access of energy resources to international markets in the short term, supply and pricing, and development plans and policies in the long term. Although there are no problems in terms of reserves in oil and natural gas supply for the next few decades, issues such as searching, producing, and delivering new reserves seem to remain the main problem areas affecting international relations. Population and income growth are the main factors that cause increase in energy consumption. The recent population growth, especially in non-Western countries, and the rapid industrialization and

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urbanization of these countries have led to major increases in primary energy demand such as oil and natural gas. As the world economy grows, the desire for fast delivery of products for trade countries has made it important to use the existing energy resources effectively and then to obtain cheap and clean energy resources. In order to meet the energy needs, imported energy sources have been used, and high-cost investments based on fossil-based fuel imports have been made, and foreign dependency in energy has reached serious levels for many countries. The aviation industry is a fast growing sector, which is the only network that provides the possibility of rapid worldwide transport. Air transport is becoming more popular in world trade, tourism and travelling, the connection of companies for meetings and conferences, and many other businesses. It is a convenient way of bridging large distances in relatively short time [1]. One of the most important factors that determines the transportation cost in the aviation sector is the fuels used in planes. On the other hand, as a result of the increase in fossil fuel consumption in the aviation sector, it causes environmental problems due to the harmful and toxic gases such as CO_2, SO_2 and NO_x [2, 3]. By 2020, global international aviation emissions are projected to be around 70% higher than that of 2005; and the International Civil Aviation Organization (ICAO) forecasts that by 2050 they could grow by a further 300-700% [4]. The International Energy Agency (IEA) has reported that the world will need 50% more energy in 2030 than it needs today due to the transportation sector becoming as the second largest energy consuming sector after the industrial sector. Mostly, transportation sector sourced from fossil fuels consumes more than 90% of petroleum while a small amount is sourced from natural gas and renewable energy sources [9, 10]. As the demand for energy increases, the conventional oil and natural gas reserves that can be commercially exploited will diminish after approximately 41.8 and 60.3 years, respectively [11]. Therefore, in order to limit the negative consequences of climate change, priority and significance should be given to new and renewable energy sources, not fossil fuels [12]. For many years, efforts have been made to use alternative fuels to eliminate these problems in road vehicles, and countries encourage the use of biofuels both to protect the environment and to reduce their dependence on import petroleum. Similarly, in the aviation sector, this has led to the need to identify this potential and examine the availability of alternative fuels. In the studies carried out for this purpose, the necessity of the use of biofuels in the aviation industry and the characteristics of alternative fuel types that can be used were examined. As a result, thanks to the fuel systems and unique designs of the aircraft to be produced in the future, it is evaluated that alternative fuels that can be used in internal combustion engines and gas turbines may have similar properties, and this will contribute to economic development and environmental protection by creating a fuel union in road and air transport [13]. However, it is a known fact that fuel also significantly affects the potential of reducing greenhouse gas emissions. Four certified pathways to produce bio-jet fuels are described here and shown in Fig.1.

Among these alternative methods and fuels, blending and using biodiesel with different proportions of jet fuels has become very popular recently. Commercial aviation fuel is fossil-sourced, and the concern that fuels may perish over time raises a number of concerns regarding the safety of fuels. In addition, jet fuel production studies from solar energy and carbon dioxide are thought to take quite a long time. This requires aviation industry stakeholders to have cost-effective, environmentally friendly and sufficient fuel supplies that can be used in existing and future fleets. As a result, various airline companies, aircraft manufacturers and engine manufacturers, as well as other industry participants, are collaborating with biofuel suppliers to test renewable jet fuel mixtures in existing engines both on the ground and in the sky [15].

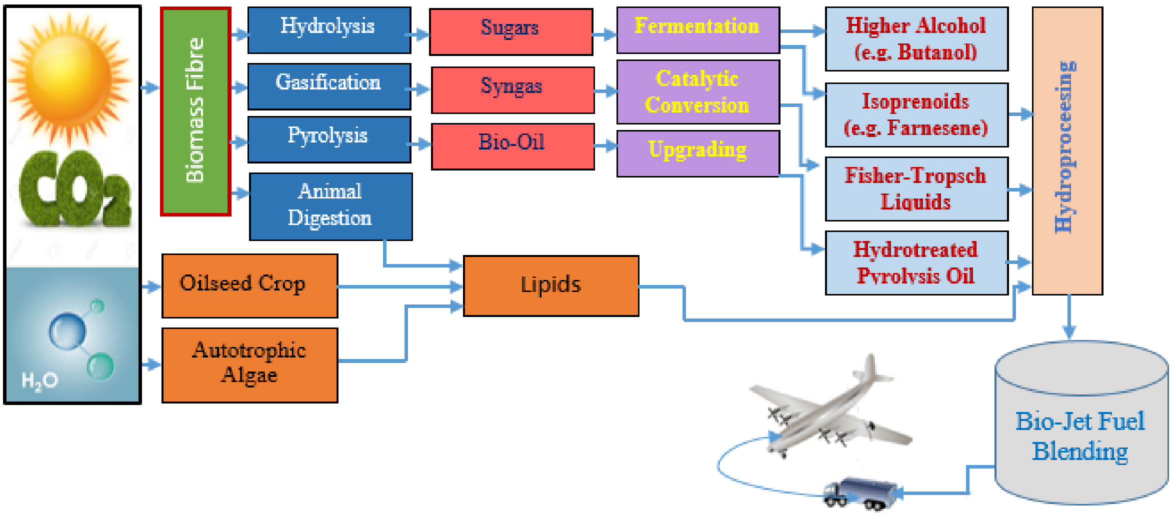

Figure 1. A simplified schematic diagram of different technology pathways to bio-jet fuel [14]

Over the past five years, several commercial routes have been flown using blends of biofuels and conventional jet fuel. For instance, in 2008, Air New Zealand flew a Boeing 747 from Auckland to Wellington with one of its four engine fuelled with a blend of 50% hydro-processed jatropha seeds and 50% Jet A1. In late 2011, KLM Royal Dutch Airlines launched a series of 100 flights from Amsterdam to Paris powered by a 50% blend of camelina-derived biofuel, followed by 100 more flights in February 2012 using cooking oil-derived biofuel. Similarly, between July and December 2012, Lufthansa performed a long-term evaluation of Hydro-processed Esters and Fatty Acids (HEFA) kerosene on 1187 flights from Hamburg to Frankfurt [16]. The International Air Transport Association aspires to use 6% biofuel blends in aircraft by 2020 and several test flights have already been performed using blends of conventional jet fuel and bio-jet fuel from algae, camelina, jatropha and other plant-based feedstocks for both commercial airliners and military aircraft. Sustainability remains the main concern in order for biofuels to become the source of jet fuel; notably, the ability for the biofuel to conserve ecological balance, productivity, biodiversity and natural resources. Use of biofuels with jet fuels is undoubtedly expected to be an improvement in reducing emissions [17]. Payan et al. [18] addressed environmental studies of alternative fuels and analysed the relative greenhouse gas (GHG) emission reduction for biomass sources compared to conventional jet fuel based on fossil sources and its blend. The results are summarized in Table 1.

As can be seen in Table 2, when compared to conventional fossil fuel sources, while raw material having the highest GHG emission is Jatropha with 42%, the raw material having the lowest emission is found to be Wood Residues with 148%. The increase in trade, through both inter-region and inter-country, demonstrates the importance of the transportation sector in terms of country economy with globalization. Airway is one of the means, which is used for carrying and transporting both people and products or services from one place to another with various purposes. The global fuel consumption by commercial airlines has increased each year since 2009, and is predicted to reach an all-time high of 98 billion gallons in 2020. While the great recession created a slight decrease in consumption over 2008 and 2009, by 2011 consumption levels had recovered to exceed pre-recession levels. Fig. 2 shows the total fuel consumption of commercial airlines worldwide between 2005 and 2020 [19]

Table 1. Relative GHG emission reductions for biomass sources compared to fossil sources [18].

Biomass Feedstock	GHG Emission Reduction Compared to Conventional Jet Fuel (%)
Jatropha	42
Canola	44
Corn Stover	55
Switchgrass	63
Miscanthus	72
Camelina	86
Waste Fat	87
Algae	124
Sweet Sorghum	133
SRCW	145
Wood Residues	148

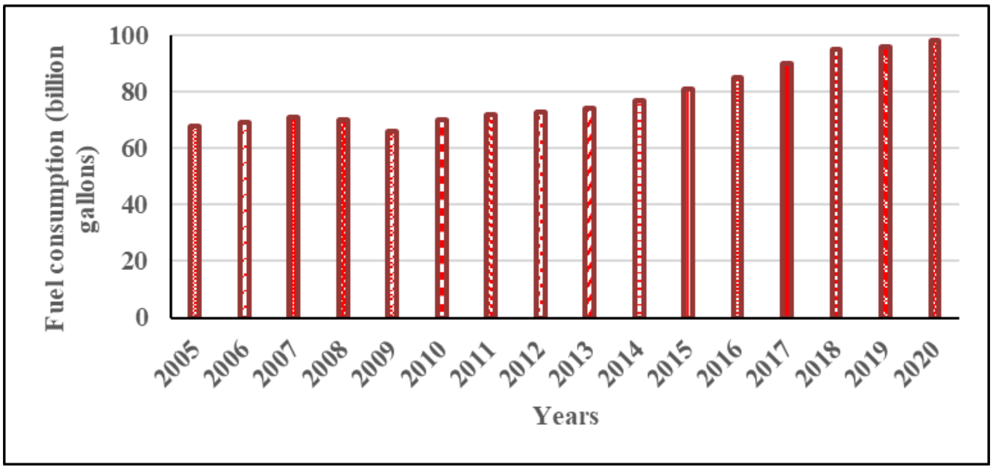

Figure.2. Total fuel consumption of commercial airlines worldwide between 2005 and 20120 (in billion gallons)

2. Materials and Methods

The fuel properties of biodiesel vary greatly depending on the fatty acid distribution [20]. The most important features are ignition ability, cold flow properties and oxidative stability. Although saturation and fatty acid distribution in lipids do not have a significant effect on the production of biodiesel by the transesterification method, it is directly associated with the properties of the fuel. For example, biodiesel fuels produced from saturated oils have a high cetane number and very strong oxidative stability, while exhibiting lower combustion properties. Biodiesel fuels produced from saturated fat tend to gel at ambient temperatures. Biodiesel produced from long chain unsaturated fatty acid rich raw material has good cold flow property. However, the tendency of these fatty acids to oxidize is very high when compared to others. Therefore, problems may arise during the long-term storage of biodiesel [21].

The analyses of fatty acid composition of the oils were conducted by Dicle University Science and Technology Application and Research Centre (DÜBTAM). The fatty acid profile of the vegetable oils used in this study is summarized in Table 2.

Table 2. Fatty acid compositions of oils (wt.%)

Fatty acid	C:D	Closed Formula	Algae	Sunflower	Cotton	Canola	WCO
Lauric	C12:0	$C_{12}H_{24}O_2$	---	---	---	---	---
Myristic	C14:0	$C_{14}H_{28}O_2$	---	0.075	0.686	0.045	0.13
Palmitic	C16:0	$C_{16}H_{32}O_2$	15.64	5.933	21.468	6.234	8.80
Palmitoleic	C16:1	$C_{16}H_{30}O_2$	0.324	0.144	0.556	0.342	---
Stearic	C18:0	$C_{18}H_{36}O_2$	2.108	3.442	2.607	2.486	4.20
Oleic	C18:1	$C_{18}H_{34}O$	54.89	36.224	18.214	61.455	45.15
Linoleic	C18:2	$C_{18}H_{32}O_2$	19.56	52.945	55.446	22.124	39.74
Linolenic	C18:3	$C_{18}H_{30}O_2$	4.876	0.383	0.145	5.108	0.20
Arachidic	C20:0	$C_{20}H_{40}O_2$	2.240	0.230	0.062	1.432	0.43
Behenic	C22:0	$C_{22}H_{44}O_2$	0.334	0.456	0.144	0.366	0.75

The algae oil used in the study was obtained from a commercial company (Soley Biotechnology, Istanbul, Turkey) and the other oils were purchased from a local supermarket. In order to produce fuel suitable for the standard, Sigma-Aldrich's 99.7% purity methyl alcohol and as a catalyst Merck brand 99.9% purity potassium hydroxide (KOH) were purchased from commercial companies. In accordance with our previous studies and literature information, 65 ^{o}C temperature, 60min reaction time, 1% catalyst and 20% of methyl alcohol were determined as optimum conditions; and transesterification reactions of all oils were performed under these conditions. The properties of the biodiesel fuels produced were analysed at TÜPRAŞ Batman Refinery fuel analysis laboratory and Batman University Technical Sciences Vocational School Refinery and Petro-Chemistry Technology Program Laboratory.

3. Results and Discussion

Fuel properties of jet fuel (JP-8) and biodiesel blends mixed in different proportions are given in Table 3. Density is an important fuel property directly related to aircraft performance. Some fuel-gauging systems give readings proportional to the speed of sound; therefore, this property is also an important fuel parameter. The speed of sound in a material characterizes its susceptibility to pressure changes at constant entropy. Therefore, while density is a static property, the speed of sound provides information about effects relating to the distribution of energy on a molecular scale [22]. When biodiesel produced from different oils at the rates of 5%, 10%, 15% and 20% is added to jet fuel, the density values of the blends change as in Figure 3.

Table 3. Fuel properties of jet fuel, biodiesel fuels and their blends at various blends

FUELS		PROPERTIES			
		Density 15ºC (kg/m³)	**Kinematic Viscosity 40 ºC (mm²/s)**	**Flash Point (ºC)**	**Freezing Point (ºC)**
Raw	**Jet Fuel**	795	1.17	43.0	-55.1
	Canola	883	4.48	172.0	-11
	Algae	881	4.55	150.0	-14
	Sunflower	885	4.28	178.0	-7
	Cotton	881	4.22	175.0	-13
	WCO*	892	4.66	180.0	-8
%5B	**Canola**	800	1.23	55.5	-29.7
	Algae	801	1.25	48.0	-25.7
	Sunflower	803	1.23	53.5	-32.6
	Cotton	812	1.34	55.5	-21.4
	WCO*	818	1.54	60.1	-16.5
% 10B	**Canola**	803	1.33	60.2	-25.3
	Algae	805	1.36	49.5	-21.2
	Sunflower	809	1.32	56.2	-28.4
	Cotton	816	1.38	60.3	-18.5
	WCO*	823	1.58	65.5	-13.7
%15B	**Canola**	809	1.42	64.8	-21.4
	Algae	811	1.44	50.5	-18.6
	Sunflower	816	1.43	59.5	-24.3
	Cotton	825	1.52	62.7	-15.2
	WCO*	836	1.77	68.3	-9.7
% 20B	**Canola**	816	1.56	68.4	-17.8
	Algae	818	1.59	51.5	-15.2
	Sunflower	824	1.55	63.7	-17.1
	Cotton	830	1.64	68.5	-11.3
	WCO*	840	1.95	70.7	-5.8

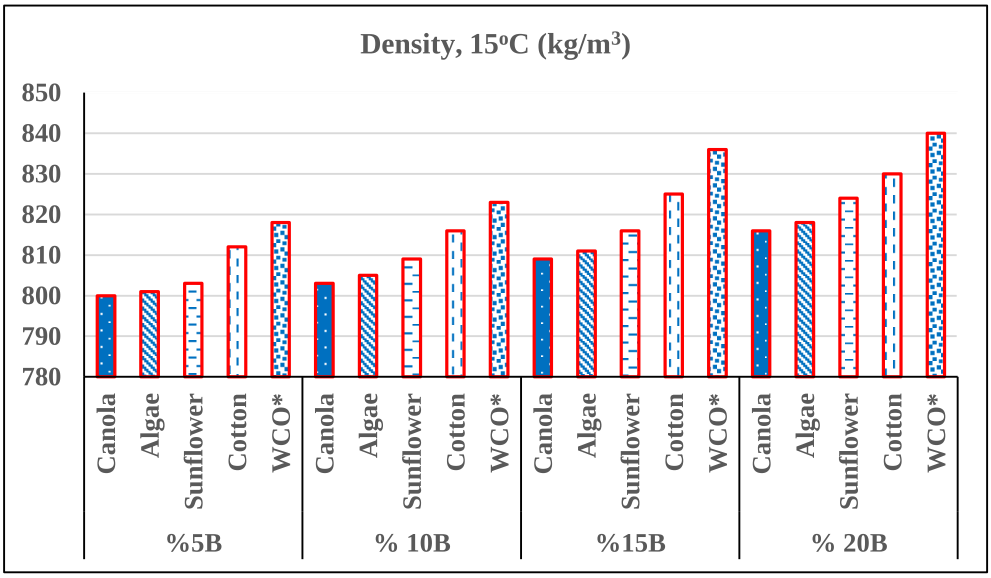

Fig. 3. Density changes of biodiesels mixed with jet fuel in different proportions

As seen in Figure 3, it is seen that when biodiesel fuels with higher density than jet fuel are mixed with jet fuel, they show a relative increase in density compared to the amount of biodiesel (%). However, all measured values appear to be within the scope of ASTM D 1298. Jet fuels are a mixture of hydrocarbons, the molecular weights of these hydrocarbons vary depending on their chain length. Therefore, it is known that the melting point and the smoke point, which have a significant effect on the quality of aviation fuel, change with the chain length of the hydrocarbon [23]. One of the important features that determine the quality of the fuels used in the aviation industry is the viscosity of the fuel. It is desirable that the fuel viscosity is quite low, since low viscosity means that the fuel comes to the engine combustion chamber without problems[24]. Apart from these features, jet fuels must not have any water other than the amount specified in the standards. If there is too much water in the fuel, the risk of freezing of the fuel will increase as the aircraft rises high. Freezing of the fuel will disrupt or interrupt the fuel flow to the turbines. This can cause turbines to malfunction. The high viscosity of jet fuels is an important problem for the injection nozzles of the turbines. In such a case, during fuel injection, the nozzles need to use more energy to spray the fuel. If this problem is not resolved, it will shorten the working life of the injection nozzles, resulting in higher maintenance costs and re-ignition the engine in the event of a malfunction during flight. It also affects the pressure drop in high viscosity fuel lines [25]. As a consequence, the fuel pump must work harder to guarantee a constant flow rate so that the turbines can continue working as required [26, 27]. In Figure 4, there are the viscosity values of jet fuel + biodiesel blends obtained with biodiesel mixed with jet fuel at different rates measured at 40 ^{o}C. It is seen that all of the determined values are below 2 mm^2/ s. This predicts that the mixture obtained by adding up to 20% of biodiesel into jet fuel will not be a problem in terms of viscosity.

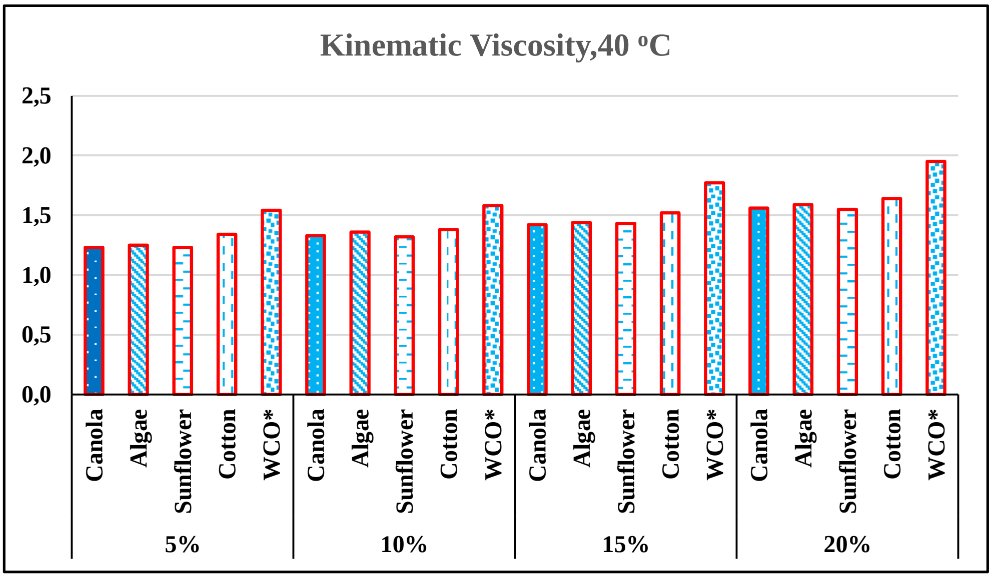

Fig. 4. Viscosity changes of biodiesels mixed with jet fuel in different proportions

The flash point of a volatile material is the lowest temperature at which its vapours ignite if given an ignition source [28, 29]. The flash point is sometimes confused with the auto-ignition temperature, the temperature that causes spontaneous ignition. The fire point is the lowest temperature at which the vapours keep burning after the ignition source is removed. It is higher than the flash point, because at the flash point more vapour may not be produced fast enough to sustain combustion [30].

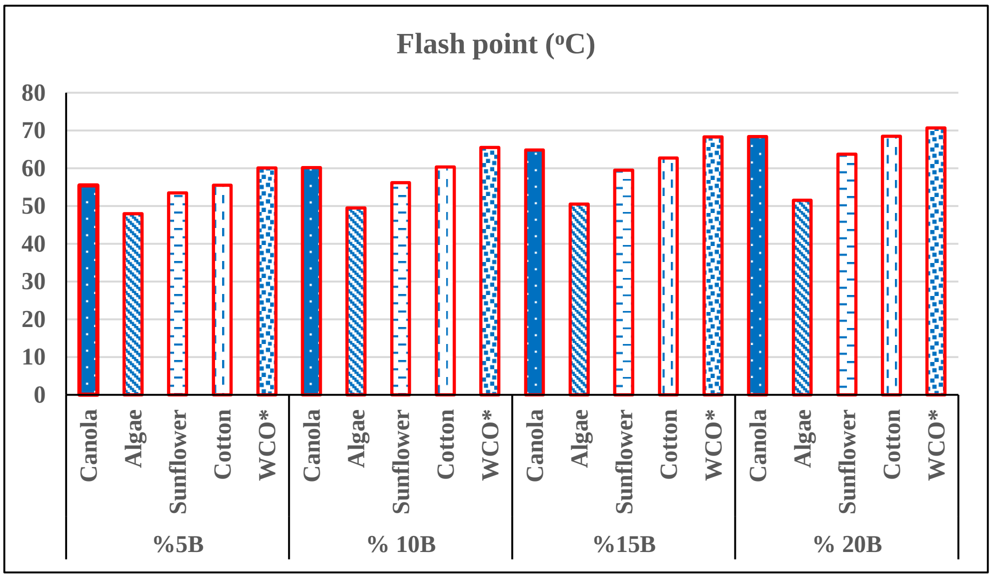

Fig. 5. Flash point changes of biodiesels mixed with jet fuel in different proportions

When biodiesel produced from different oils at 5%, 10%, 15% and 20% ratios is added to the jet fuel, the flash point values of the mixtures change as in figure 5. It is seen that all of the obtained results are within the scope of ASTM D 3828 values. Therefore, it is thought that when 20% of the biodiesel used in this study is added to the jet fuel, it will not be a problem in terms of the Flash Point feature.

Freezing point is an important quality specification for jet fuel [31]. This is the temperature at which components in the fuel start to solidify into wax crystal [32]. Freezing point is measured as the temperature at which the last wax crystal melts when warming a fuel that has previously been cooled until wax crystals formed [33]. At very low temperatures, aviation fuels will develop solid hydrocarbon crystals. The freezing point test for aviation fuels was developed to determine the temperature at which these crystals completely disappear. The freezing point test is important for aviation fuels since impeding fuel flow can have catastrophic effects for aircraft such as interfering with the atomisation of the fuel [34].

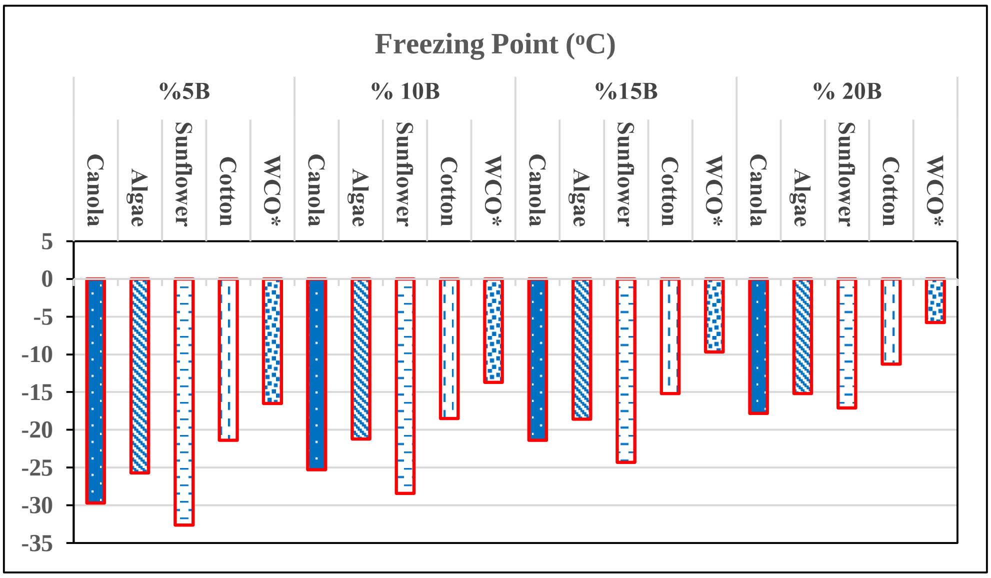

Fig. 6. Freezing point changes of biodiesels mixed with jet fuel in different proportions

As seen in Figure 6, when the biodiesel used in the study was added to the jet fuel in different proportions (5%, 10%, 15% and 20%) and freezing points of the mixtures were measured, a significant increase was found in the values. This suggests that fuel mixtures may cause some problems in the engine as the aircraft height increases. However, it is anticipated that this problem can be solved with additional freezing point reducing additives and appropriate amount of biodiesel.

4. Conclusions

The main purpose of this study is to determine the density, viscosity, flash point and freezing point values of the fuel mixtures obtained by adding 5%, 10%, 15% and 20% ratios (v/v) of different biodiesel blends into jet fuel. The fatty acid compositions of the oils used in the study were measured and the effects of the biodiesel fuels produced from various oils on the fuel quality were determined. Considering the properties of the biodiesel used, it is seen that the fuel with the highest density, viscosity, flash point and freezing point is WCO (892 kg/m^3, 4.66 mm^2/s, 180 ^{o}C, -8 ^{o}C). As a result, values of WCO biodiesel blends were found to be higher than other blends. In addition, it was determined that the Algae biodiesel used in the study has the best density (881 kg/m^3), Flash point (150 ^{o}C) and Freezing point (-14 ^{o}C), and the cotton biodiesel meets the most suitable viscosity value. When we look at the mixtures we used in this study, it is seen that all values except freezing point values comply with the standards. It is thought that the freezing point problem in the blends can be overcome by using suitable additives and appropriate proportions.

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