Cold Flow Properties of Biojet Fuels in Aviation

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1 Introduction

The fact that the fuels used for transportation in the world are of fossil origin leads to both more pollution of the environment and the gradual depletion of reserves. To protect the environment and reduce dependence on fossil fuels, alternative solutions to existing non-renewable resources are needed. The use of alternative fuels contributes to the reduction of emissions from fossil-derived fuels and to the economy of countries by reducing foreign dependence (Acaroğlu, 2013; Bouriazos et al., 2014; Köse, 2018; Ozcanli et al., 2013).

In this study, it is easy to grow, low cost and has no food value for humans and animals due to its thorny structure, causing crop losses in agricultural lands. This study aimed to produce an alternative biojet fuel by obtaining biofuel from the *Onopordum* plant and mixing it with certain amounts of aviation fuel. The new fuel obtained will both reduce the impact of emissions from conventional jet fuel on the environment and contribute to the economy of the country. In addition, some additives will be added to the biojet fuel obtained to improve the cold flow properties, which are of great importance in aviation fuels.

Jet fuels from renewable raw materials can reduce the aviation industry's dependence on a single energy source, prevent oil price fluctuations, and reduce greenhouse gas emissions (ATAG, 2011; ICAO, 2013). Therefore, the use of cleaner alternative fuels in the aviation industry will significantly improve the environment. Biomass-sourced jet (biojet) fuel has become an important element in the aviation industry's strategy to reduce operating costs and environmental impacts (Sgouridis, 2014). Biomass-based jet fuel has lower environmental impacts than petroleum-derived fuels and aviation industry and military petroleum fuels and may provide a

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Table 1 Properties of JP-8 and *Onopordum* biodiesel fuel

Properties	Unit	JP-8 (NATO F-34)	*Onopordum* biodiesel
Density	kg/l	0.775–0.840	0.883
Kinematic viscosity	mm^2/s	8 (−20° C)	3.5 (40° C)
CP	°C	–	−2.5
FP	°C	−47.0	−5.0
Flash point	°C	38	180
Ho	MJ/kg	42.8	40.0

good long-term solution (Asiedu et al., 2019; Dangol et al., 2017; Wang & Tao, 2016). In this study, JP-8 military aviation fuel was used as the experimental fuel. The characteristics of JP-8 fuel are shown in Table 1.

One of the most important problems of biodiesel is its cold flow properties such as cloud point, pour point, freezing point, and cold filter clogging point, which are worse than aviation fuels. Biojet fuel to be used as a fuel in the aviation industry, it must be within the limits given in aviation fuel standards. In this study, pure blank and PMA additives were added to regulate the cold flow properties of the new biojet fuel, which is obtained by mixing biodiesel fuel with JP-8 fuel in various proportions, as an aviation fuel. After the fuel properties were determined, the results were examined and the compliance of the obtained fuels with the JP-8 fuel standard was checked.

2 Material and Method

The experiment carried out in this study consists of two stages. The first stage of the experiment is to produce biodiesel from the oil of *Onopordum* plants. Biodiesel was produced from the obtained crude oil by transesterification method accompanied by alcohol and catalyst. The biodiesel used for the experiment is manufactured in accordance with EN 14214 standard. The second stage of the experiment is to obtain a biojet fuel that can be an alternative to aviation fuels. For this purpose, certain proportions of JP-8 fuel used in the aviation sector (%2, %3, %5) were mixed with the biodiesel produced from *Onopordum* oil. Then, the properties of the fuel mixtures obtained by adding cold flow additives (PMA) to improve the cold flow properties of the prepared fuel mixtures were studied. Crude oil obtained from the seeds of *Onopordum* plants was used for biodiesel production. JP-8 has been accepted as a uniform fuel for military use by NATO countries in 1988. The properties of JP-8 (NATO F-34) fuel are given in Table 1. To produce biojet fuel, blends of B2, B3, and B5 with JP-8 fuel and *Onopordum* biodiesel were prepared (Table 1). To improve the fuel properties, some cold flow improver additives have been used to be added to aviation fuel and biojet fuel. PMA, TBHQ, BHT and Pentanol additives were used to test the cold flow properties (Bhale et al., 2009). In the process of biodiesel production, biodiesel reactor, precision scales, magnetic stirrer, thermometer, stopwatch, and free fatty acid measuring device were used. In determining the properties of all fuels and their mixtures; Density, kinematic viscosity, calorimeter, cold filter plugging point, cloud and pour point measuring device were used Acaroğlu (2013).

The cold filter plugging point value of all fuels and fuel mixtures was measured with an AFP-102 Model from Tanaka (Acaroğlu et al., 2018; Dehaghani & Rahimi, 2018). The cloud point and pour point values of all fuels and fuel mixtures were measured with a device purchased from Polyscience. This device can measure in accordance with ASTM D 97 standards (Onurbaş Avcıoğlu et al., 2011). Transesterification method was used to obtain biofuel from *Onopordum* plant. After the production of biodiesel, the fuel mixtures were prepared (Monirul et al., 2017; Ozcanli et al., 2013). In this experiment, which was carried out to determine the effect of biofuel mixtures on fuel properties in aviation fuels, 2%, 3% and 5% *Onopordum* biofuel was added to JP-8 fuel, which is one of the aviation fuels, to obtain biojet fuels ((Altaie et al., 2015; Elias et al., 2016; Serrano et al., 2014; Sorate & Bhale, 2015). In addition, to determine the effect of the additives on the cold flow properties of the fuel, the fuel properties were tested by adding certain ratios of PMA additives to the fuels. Just before starting the tests, the fuel mixtures were mixed at 600 rpm for 15 min using a thermomagnetic mixer at room temperature to obtain a homogeneous mixture in the tests (Acaroğlu, 2013; Özcanli et al., 2012). AF-1, AF-3, ..., AF-27 are single digits without additives, AF-2, AF-4, ..., AF-28 are fuels with 0.005% (by weight) PMA additives.

3 Research Results and Discussion

The fuel mixtures prepared for the experiment and the additives added to the mixtures are given in Table 2.

The pure density value of JP-8 fuel was measured as 0.7897 kg/l. While the densities remained the same according to the mixing ratios of the fuel and additives, the kinematic viscosity values showed little variation. The fuel with the highest density was AF-28 fuel with a value of 0.7917 kg/l, and the fuel with the lowest density was AF-23 fuel with a value of 0.787 kg/l. The viscosity value of JP-8 fuel without additives was 1.38 mm^2/s. The fuel with the highest kinematic viscosity was AF-20 fuel with a value of 1.54 mm^2/s. The viscosity values of AF-19 and AF-21 fuels were the same as those of the JP-8 fuel used in the experiments.

According to the test results, the cold filter plugging point of the pure JP-8 fuel was −20 °C, cloud point −23.3 °C, pour point −31.13 °C, and freezing point −47 °C (Benjumea et al., 2007; Chiu et al., 2004; Ming et al., 2005; Soriano Jr et al., 2006). According to the figure, the cold filter plugging, clouding, pour and freezing point values of AF-6 fuel were, respectively, −23 °C, −26.15 °C, −34.265 °C, and − 52 °C. These values show that AF-6 fuel has the best cold flow properties. After AF-6 fuel, the fuel with the best CFPP and FP point among biodiesel blended fuels are AF-13 fuel with the best CP and PP point is AF-21. It has been observed that

Table 2 Alternative fuel blends to JP-8 Fuel

Fuels	Code	KV (40 oC mm^2/s)	Ho (MJ/kg)	Density (kg/l)	CFPP	CP	PP	FP
JP8	AF-6	1.45	46.095	0.7896	−23	−26.15	−34.265	−52
B2	AF-13	1.45	45.622	0.7885	−22	−25.20	−33.22	−51
B3	AF-21	1.38	45.709	0.7894	−22	−25.50	−33.55	−50
JP8	AF-7	1.35	46.121	0.7899	−21	−24.25	−32.175	−50
B2	AF-14	1.35	45.697	0.789	−20	−23.30	−31.13	−50
JP8	AF-2	1.40	45.81	0.790	−22	−25.50	−33.55	−49
B5	AF-27	1.32	46.136	0.7909	−21	−24.50	−32.45	−49
JP8	AF-3	1.43	45.849	0.790	−21	−24.25	−32.175	−49
B3	AF-20	1.54	45.602	0.7891	−21	−24.25	−32.175	−49
B3	AF-16	1.40	45.642	0.7893	−21	−24.50	−32.45	−48
JP8	AF-4	1.35	46.459	0.7897	−21	−24.25	−32.175	−48
B2	AF-9	1.46	45.712	0.7916	−21	−24.25	−32.175	−48
JP8	AF-5	1.31	45.779	0,7896	−20	−23.50	−31.35	−48
B2	AF-10	1.36	45.561	0,7913	−20	−23.50	−31.35	−48
B5	AF-28	1.34	46.348	0,7917	−20	−23.50	−31.35	−47
JP8	AF-1	1.38	46.574	0,7897	−20	−23.30	−31.13	−47
B2	AF-11	1.45	45.593	0,7914	−20	−23.30	−31.13	−47
B2	AF-12	1.31	45.582	0,7916	−19	−22.50	−30.25	−47
B3	AF-17	1.33	45.663	0,7891	−19	−22.50	−30.25	−47

AF-6 fuel has the best cold filter plugging point value, with a value of −23 °C, which is nearest to the density of JP-8 fuel. Considering the relationship between density and CFPP, the effect of additives is clearly visible. Although the densities remained more or less the same, it is seen that the fuel values of AF-6 and AF-21 have improved.

While there was not much change in the density values according to the mixing ratios of the fuel and additives, the kinematic viscosity values showed little variation. The fuel with the best cold flow properties among the witness fuels is AF-21, whose CFPP, CP, PP, and FP values are −22 °C, −25.5 °C, −33.55 °C, and −50 °C, respectively. According to the test results, the fuel with the highest calorific value is AF-28 fuel, and the fuel with the lowest calorific value is AF-24 fuel. Although the addition of other additives has reduced the calorific value, the values found are in the range of values suitable for fuel standards. While the density values remained the same according to the mixing ratios of biodiesel and additives, the kinematic viscosity values showed little variation. The viscosity value of AF-25 fuel (B5 + PMA additive fuel) was observed to be at the nearest value to the viscosity value of JP-8 fuel used in the experiments. With the PMA additive, cold filter plugging point, cloud point, and pour point values of all non-additive fuels were reduced by approximately −3 °C, and the freezing point value was reduced by approximately −5 °C. For all values, the PMA additive gave the best effect in improving the cold flow properties when used together with the TBHQ additive, followed by PMA-pentanol and then PMA-BHT blends, respectively. The fuel with the highest heating value is AF-1 fuel, followed by AF-27 fuel with biodiesel blend after AF-4 and AF-6 fuels. It is observed that the PMA additive stabilizes the viscosity, density, and heating values.

4 Conclusions and Recommendations

4.1 Results

In this study, to obtain biojet fuel from the *Onopordum* crops, which has no nutritional value, does not need irrigation and can be grown easily, experiments have been carried out and the results have been examined and alternative fuels to JP-8 fuel have been found. B2, B3, and B5 fuel mixtures formed by mixing *Onopordum* biofuel and JP-8 fuel in certain proportions were used in the experiments, and PMA additives were added to the mixtures in certain proportions to improve the cold flow properties of these fuels. According to the test results, it has been observed that there are many fuel mixtures that can be used as alternatives to JP-8 fuel and even have more advanced fuel properties. The kinematic viscosity, density, and calorific values of all test fuels comply with JP-8 fuel standards. However, the freezing point value of some mixtures does not comply with the JP-8 fuel standard.

The search for alternative fuels has accelerated due to depletion of fossil fuels and the ever-increasing energy need worldwide. The properties of pure B2, B3, and B5 fuels remained below JP-8 standards. However, addition of additives to these fuels showed improved fuel properties, and many fuels have been brought into compliance with the standards. It was concluded that the PMA mixture among the additives had the best effect on improving the fuel properties. In addition to JP-8 fuel, B2 fuel mixtures are shown to exhibit the best fuel properties. Addition of 0.05 (%w) PMA additives and the use of B2 fuel mixtures as an alternative to JP-8 fuel will significantly improve the cold flow properties of jet fuels. *This is the first study on Onopordum biofuel, and it is possible to test the additives added to the fuel mixtures with different ratios or to produce different alternative fuels by diversifying the types of additives used.* Future studies should focus on the analysis of engine performance values of the biojet fuels with additives and on the development of the most suitable additive mixtures based on the values obtained in this study.

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