Bio-Based Jet Fuel Production by Transesterification of Nettle Seeds

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ABSTRACT

The use of petroleum-based fuels in air transport and the increase in oil prices over the years have increased fuel costs. Due to this increase, fuel manufacturers and airline companies have started to search for alternative fuels. Since aviation has an important place in the transportation sector, biomass has the greatest potential in the search for renewable energy sources. Biological substances of plant and animal origin and containing carbon compounds are energy sources, and the fuels produced from them are called biofuels. Biofuels are an important source of sustainable energy, which greatly reduces the greenhouse gas effect, improves weather conditions, reduces dependence on oil produced from fossil fuels, and is important for new markets. The nettle seed oil used in the current study was purchased from the local market and was obtained using the cold-pressing method at low temperatures. After the completion of the transesterification process, a two-phase mixture consisting of biofuel-glycerin was obtained, and the upper phase containing fatty acids was taken and transferred to a clean tube. After the final washing processes, bio jet fuel was obtained by adding chemicals at certain rates. The analysis of the obtained fuel was conducted at the Tubitak Marmara Research Centre. When the report was evaluated and compared with international standards, consistent results were obtained. It can be predicted that sustainable fuels can replace fossil fuels in the future.

Keywords-sustainable energy; bio-based jet fuel; transesterification;nettle seeds

I. INTRODUCTION

Sustainable and renewable fuel production ways have an important place in terms of environmental, social, and economic aspects. Jet fuels constitute an important part of the relevant economy with a growing rapidly share [1]. When we look at the transportation sector in particular, it needs 2627.02 million tons of oil equivalent, which represents 27.9% of the total energy produced in the world [2]. In order to change the aircraft design and reduce fuel consumption, several attempts have been made to reduce CO_2 emissions, but these measures have yielded lower results than CO_2 emissions from the increase in flights [3, 4]. As a result, airline operators have sought different ways to solve this problem. Biofuels are a likely solution due to their renewable nature and low CO_2 emissions [4-6]. In addition, these fuels bring a new approach to the sector, increase safety, and reduce harmful emission particles [7-11]. Sustainable biofuels are important alternative fuels that require a large amount of raw material resources. These fuels can be obtained by means such as Ficher Troph synthesis [12-14] and alcohol synthesis [15-17], which have become known ways of sustainable fuel production using intermediates such as alcohol and synthesis gas. The goal of minimizing the CO_2 emissions in the carrying sector has become a major driver for the advance of renewable fuels [18]. According to the estimations of the International Energy Agency, it is predicted that by 2050, sustainable biofuels will supply 27% of all energy in the field of transportation. For this reason, sustainable fuels have been the focus of attention [19, 20]. Traditional fossil-based jet fuels consist of approximately 20% paraffins, 40% isoparaffins, 20% naphthenes, and 20% aromatics [19]. This composition gives physical properties such as a freezing point of -47^{o}C and 43.28MJ/kg energy [20].

Renewable bio jet energy sources consist of hydrocarbons in the boiling range of traditional fossil-based energy sources, showing that they have a structure close to the traditional fossil-based jet fuel. In the absence of aromatic compounds, harmful particles emitted from renewable bio jet fuels are lower than those emitted by fossil fuels [22].

The most accepted jet fuel standard is ASTM D1655-17 [23]. The limits of this standard allow biodiesel blending up to 50ppm, however, their use in air transport is still limited despite their advantages. Several hydrotreating routes have been proposed to manufacture renewable aviation fuel [24-30]. In addition, there have been new developments in the methods of obtaining rich aromatic and cycloparaffin hydrocarbons during the production of renewable jet fuels [31-33]. After that, the fuel standard ASTM D1655 can be limited as the high aromatic and/or cycloparaffin content in the fuel meets the density requirements, low heating value, and especially smoke point limits. To date, 5 different fuels that can be mixed with fossil-based jet fuel and used in gas turbine engines have been approved by the American Society for Testing Materials (ASTM). ASTM D7566-19 describes the detailed requirements and compositions [34].

The genus Urtica, a member of the Urticaceae family, is in the main group of Angiosperms (flowering plants) [35, 36]. The main varieties of the genus Urtica, known for their painful hairs on their leaves and stems, are Urtica dioica L., Urtica urens L., Urtica pilulifera L., Urtica cannabina L., Urtica membranacea Poiret, and Urtica kiovensis Rogoff [38]. Urtica spp. is more commonly known as nettle. It grows all over the world, especially in regions with temperate climates. It prefers open or partially shaded habitats with plenty of moisture and is often found in forests, rivers or streams, and along roadsides. It is common in Europe and North America, North Africa, and parts of the Asia [35]. Nettle seeds are rich in oil, and nettle seed oil contains monounsaturated fatty acids, which is one of the reasons why that plant is preferred in biodiesel studies. The fatty acid content of nettle seed is palmitic acid, stearic acid, oleic acid, linoleic acid [37, 39].

II. MATERIALS AND METHODS

Pure oil obtained from the nettle plant seeds was obtained. Methanol, ethanol, NaOH, fuel system anti-icing, kerosene, isooctane, nettle seed oil, and purified water were used. A single-stage basic reaction method, which is generally preferred for refined and crude vegetable oils, was used for transesterification. The flow chart of the procedure is given in Figure 3. 200ml methanol and 10g NaOH were used in appropriate proportions for every 1000ml of nettle seed oil. They were mixed with 200ml methanol in 10g NaOH for 30 minutes in a magnetic stirrer heater (Figure 1). The sodium methoxide (CH_3ONa) obtained as a result of this process was kept in an oven at 60°C in order to maintain its temperature.

Then, the nettle seed oil was heated to 70°C using a magnetic heater and CH_3ONa was added to it, and the mixture was stirred at 60-70°C for 4 hours. The mixture was left at room temperature for 120 hours for the transesterification process to be completed. At the end of this process, a two-phase mixture consisting of biofuel-glycerin was obtained, and the upper phase containing fatty acids was carefully removed with the help of a pipettor and transferred to a clean tube (Figure 2). The fatty acid-glycerin boundary part was centrifuged at 1000 rpm for 5 minutes and the fatty acid part was recovered.

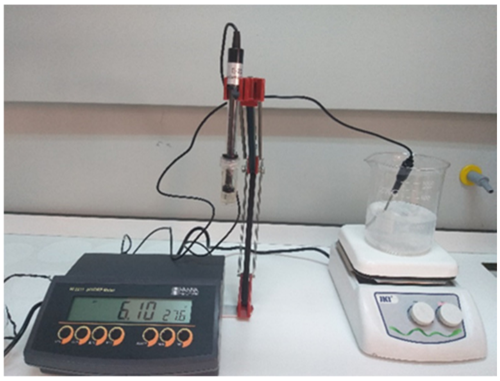

Fig. 1. Formation of CH_3ONa by a single-stage basic reaction method.

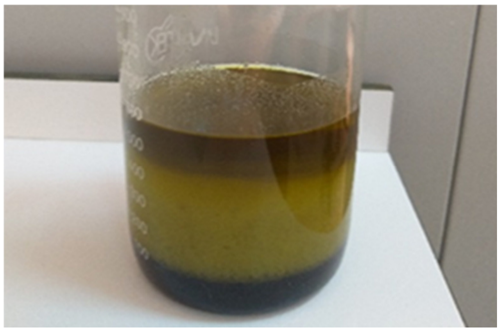

Fig. 2. Bi-phase product resulting from the transesterification process.

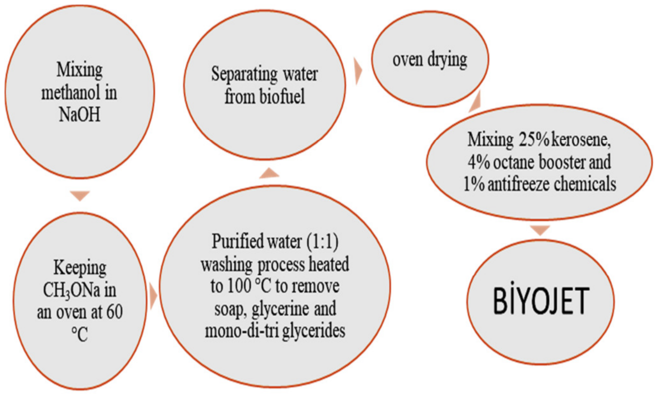

Fig. 3. Flowchart of the procedure.

In order to remove soap, glycerin and mono-di-tri glycerides that may be present in the biofuel, washing process was carried out 10 times by spraying on the biofuel using pure water (1:1) heated up to 100°C. After the last washing, the washing water was separated from the biofuel and settled to the bottom. The biofuel in the upper phase was carefully removed and dried in an oven at 110-120°C, and the remaining pure water and alcohol were completely removed. At the last stage, 3.5Lt 70% bio-based bio jet fuel were obtained by mixing 25% kerosene, 4% octane increaser, and 1% antifreeze chemicals and was sent to Tubitak Marmara Research Centre in order to determine its properties (Figure 4).

Fig. 4. Bio-based jet fuel obtained by transesterification of nettle seed

III. RESULTS AND DISCUSSION

Generally, triglycerides, lignocelluloses, and syngas are used to produce renewable aviation fuels. Biofuels can be obtained from plants, animal fats, and biomass. Especially biofuels produced from plant and organic waste reduce CO_2 emissions, in addition to reducing the dependence on fossil fuels. There are also bacteria, yeast, and algae that have the capacity to produce fuel molecules and are used in the production of biofuels. The assortment can be enhanced by modifying the existing methods or by engineering applications and synthetic means. In such applications, genetic optimization is necessary, although the selection of organisms takes up a lot of space to increase efficiency. HEFA technology is a production method of sustainable fuels. It is conducted by hydroprocessing vegetable oils and animal fats. Approximately 1.2 tons of vegetable oil is required to produce 1 ton of HEFA fuel. One of the main advantages of this technology is to integrate this process into an oil refinery (with an additional step) and eliminate the need to develop a dedicated production facility. The HEFA production process is proven and approved for mixing ratios of up to 50%. In addition, current investments in infrastructure show that the process has an economically viable scope in the near future. In our study, a 70% biological-based mixture was tried and successful results were obtained.

Pure vegetable oil cannot be used as fuel in aircraft gas turbines. For this reason, its combustion characteristics should be approximated to diesel. Four techniques can be used for fuel regulation, aiming to reduce viscosity and eliminate atomization problems. These techniques are heating, dilution/mixing, microemulsion ,and transesterification. The jet fuel sample produced with nettle seed oil was analyzed in the laboratory in accordance with the international standards. The characteristics of the fuel produced in our study and its comparison with the standards are given in Table I. As a result, it has been concluded that the characteristics of the fuel are compatible with the characteristics determined by international authorities. The distillation profile is made in accordance with the ASTM D 86 standard test. By evaporation and recondensation of 100ml sample, the temperatures at which 5, 10, 20, and 30 volume fractions were collected and determined, and a temperature-volume curve, i.e. a distillation profile, was obtained. A highly volatile fuel makes the engine easier to start, but increases problems such as vapor plugging, icing, and fuel-scalding. In order to minimize these problems, it is necessary to balance the volatility characteristics of avgas. The distillation graph of the produced jet fuel is given in Figure 5.

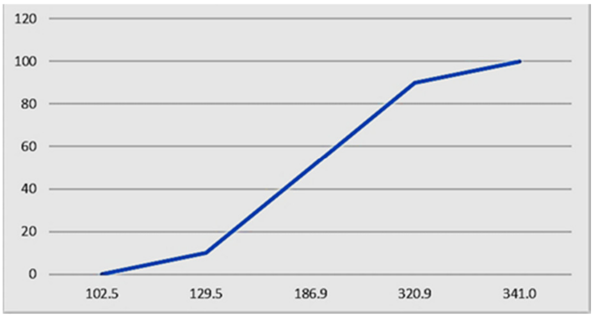

Fig. 5. Distillation graph of the bio-based jet fuel obtained with transesterification of nettle seeds.

Fuel instability is a process of multi-step oxidation reactions that occur between some of the compounds it contains. The initial reaction products are hydroperoxides and peroxides. These products are dissolved in the fuel, but they affect the elastomeric materials of the fuel system and shorten its useful life. In addition, soluble gum and insoluble particles are formed with the ongoing reactions. These substances clog fuel filters and cause residue to build up on fuel system walls, making it difficult for fuel to flow. The existing gum and potential gum values in our product are in the range of values that are quite suitable for use. The bio jet fuels studied before include 50% sustainability, while the product in our study has 70% sustainability [38]. We have previously discussed the fuel additives used with a detailed unit analysis [39]. Factors that act as drivers for switching from one fuel to another to improve energy efficiency have been identified in the literature, including various performance parameters that support environmental protection [40]. Biofuel has been previously produced using cheap waste cooking oil collected from Pakistan's Nawabshah local market [41]. The fuel produced in our study will provide a very good approach in the aviation industry.

IV. CONCLUSION

Air transport is a feature of our modern, globalized world that connects people, commerce, and most importantly, businesses across continents. The benefits and importance of air travel are undisputed, but there are also important aspects to consider. Traditionally, environmental problems involving aviation have focused on noise and air pollution and the recent issue of global climate change has focused the attention on the CO_2 emission volumes of airplanes. When greenhouse gases produced from fuels burned in flights are emitted into the atmosphere, they have a significant negative impact on the environment. Aviation is likely to need around 450-500 million tons of sustainable aviation fuel per year by 2050. Jet fuels produced using renewable bio-based are important for the aviation industry and reduce its dependency on fossil fuels. It an important breakthrough, as it will contribute to the targets of reducing emissions against global problems.

TABLE I. ANALYSIS RESULTS OF BIO-BASED JET FUEL OBTAINED BY TRANSESTERIFICATION OF NETTLE SEEDS

Parameter	Jet a	Jet b	Analysis result	Analysis method
Density (15°C)	775-840	751-802	803.5 kg/m^3	ASTMD 4052
Distillation				ASTMD 86
Initial boiling point	151.5	152.7	102.5 °C	
%10	205		129.5 °C	
%50	200	190	186.9 °C	
%90	246.7	245	320.9 °C	
Ultimate boiling point	300		341.0 °C	
Distillation residue	1.5	1.5	0.8%v/v	
Distillation loss	1.5	1.5	0.2%v/v	
Flash point	38	-	16.5 °C	ASTMD 3228
Color (saybond)	-	-	-15	ASTMD 6045
Electrical conductivity	500-600	-	504 pS/m	ASTMD 2624
Copperstrip corrosion 2h100 °C	1b	-	1b	ASTMD 130
Mercaptan sulfur	0.003	--	0.0004%m/m	ASTMD 3227
Acid number	0.1		<0.1 mgKOH/g	ASTMD 664
Current gum	2000	2000	2254mg/100mL	ASTMD 381
Potential gum	-	--	3454 mg/100mL	ASTMD873
Sulfur	-	-	0.064%m/m	ASTMD 4294
Kinematic viscosity	8	-	3.948 mm^2/s	ASTMD 445
Doctor test	-	-	NEGATIF	TS 2884
Freezing point	-40. -47	-50	-31 °C	ASTMD 2386
Smoke point	25	25	26 mm	ASTMD 1322
Heat of combustion	42.8	42.8	43.3MJ/kg	ASTMD 3338
FIA aromatic	15-25	25	17.7%v/v	ASTMD 1319
FIA olefin	%0.2- %35	-	0.9%v/v	
FIA saturated	-	-	81.4%v/v	
Thermal stability				
Control temperature 260 °C min	450	450	450mL	ASTMD 3241
Pressure difference	-	-	252mmHg	
Heating pipe sediment class	1	1	<3	
Water reaction	3	3	4 mL	ASTMD 1094
Aniline point			54	ASTMD 611-A
Octane number RON	0-100	0-100	50.1	ASTMD 2699
Octane number MON	0-100	0-100	48.0	ASTMD 2700

The current project deals with aspects such as global warming, sustainability, and reduction of carbon emissions. Unlike the previously produced planetary fuels, the proposed fuel is not separated due to its high efficiency and 70% biological nature. In conclusion, the biojet fuel under study is produced using a sustainable resource, nettle seed oil, and is an excellent candidate product, with the highest biological rate.

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