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Investigation of the Effects of Alcohol and Anti-Icing Additives on the Properties of Jet Fuel

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Abstract: In this study, the effects of methanol, ethanol, isopropanol, and Diethylene glycol monomethyl ether (di-EGME) added to jet fuel in certain proportions on the properties of jet fuel such as density, viscosity, freezing point, and ignition point was examined. By adding 2%, 5%, 7%, and 10% of each additive to JP-8 fuel, the required mixture was obtained and tested in the relevant devices. As a result of the experiments, it was determined that the density value of JP-8 fuel was 797 kg/m^3 and this value did not vary greatly in the mixed ethanol, ethanol, and isopropanol, but with the addition of di-EGME, it increased significantly and reached 814.5 kg/m^3. It was observed that the viscosity value did not vary greatly with the addition of methanol and ethanol but increased to 1.298 mm/s^2 with the addition of 10% isopropanol and to 1.98 mm/s^2 with the addition of di-EGM. The ignition point value of JP-8 fuel, which is 46 °C, was measured to be 40 °C with the addition of 10% methanol, 43.4 °C with the addition of 10% ethanol, 42.9 °C with the addition of 10% isopropanol, and 55.4 °C with the addition of di-EGM. The freezing point value of JP-8 fuel, which is -56.7 °C, was measured as -61.7 °C with the addition of 10% methanol, -62.1 °C with the addition of 10% of ethanol, -57.6 °C with the addition of 10% isopropanol and -54.6 °C with the addition of di-EGM.

Keywords: Ethanol, isopropanol, jet fuel, methanol, viscosity, density.

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1. INTRODUCTION

Energy, which is at the center of sustainable development, is used to transform economies and societies, encourage industrialization, and raise living standards, as well as to meet basic human needs such as nutrition, heating, cooling, and lighting. Energy access can be defined as access to clean and modern energy at reliable and affordable costs. Accessible and clean energy, which is a part of sustainable development, is very important for people's livelihoods and the economic growth of countries, but it is a goal that is not easy to reach. Access to energy directly affects people, cities, and countries on issues such as economic growth, food production, health, clean water, security, education, and employment (1). Today, countries struggle with seemingly contradictory agendas such as the security of energy supply, economic access to energy, and decarbonization of the energy sector. In energy policies, where energy supply security and price stability are at the forefront, decarbonization, and sustainability criteria have come to the fore in recent years due to the climate crisis, whose negative effects are being felt more and more. On the other hand, energy transformation, the main elements of which are renewable energy, energy efficiency, and the electrification of energy-intensive end-user sectors, has started to play a critical role in energy supply security and economic access to energy, as well as providing decarbonization with the opportunities offered by technological developments and digitalization (2).

As the world economy grows, the desire for fast delivery of products for the trading countries has made it important to use the existing energy resources effectively and then obtain cheap and clean energy resources. One of the most important factors determining the transportation cost in the aviation sector, where the majority of cargo transfers are made, especially passenger transportation by air, is the fuel used in these vehicles. Today, aircraft, using petroleum-derived fuels, harm the increase in pollutant emissions in the atmosphere. To eliminate these negativities in high-way vehicles, studies have been carried out for the use of alternative fuels for many years; therefore, the countries encourage the use of biofuels to protect the environment and reduce their dependence on oil. Similarly, determining this potential in the aviation industry and examining the usability of alternative fuels have led to this need. In studies conducted for this purpose, the necessity of using biofuels in the aviation industry and the characteristics of alternative fuel types that can be used were examined. As a result, it has been evaluated that alternative fuels that can be used in internal combustion engines and gas turbines may have similar properties, thanks to the fuel systems and original designs of the aircraft to be produced in the future, and this will contribute to economic development and environmental protection by creating a fuel union in high-way and air transport (3). In aviation, some planes can fly on biofuel, which is an alternative to fossil fuels, but these planes are experimental planes that seat only 2 people and do not serve commercial purposes. Fuels developed for commercial aircraft cannot be used alone. These fuels can be used by mixing them with jet fuels at a rate of 5-20%, but the production of biofuels is expensive compared to jet fuels because biofuel production technologies have not been developed enough for this job (4). Soon, we may see commercial aircraft flying in the skies on 100% biofuel. As part of global efforts to avoid the worst effects of climate change, the aviation industry needs to make massive reductions in carbon emissions by 2050. Although the industry will need to pursue multiple strategies, large-scale production and use of biomass-derived aviation fuels (known as bio-jet fuels) will play a critical role in decarbonizing the industry (5).

According to The New York Times issue of July 29, 2015, UPS has agreed to purchase 46 million gallons (about 174 million liters) of biodiesel for ground vehicles over the next three years. This corresponds to 12% of the petroleum-based fuel that the vehicles in the fleet consumed by 2017. It is not new for companies whose fuel costs take an important place in their expenses to try alternative fuels to reduce this, create an alternative to the endless petroleum-based fuels, and minimize the damage they cause to the environment. They have used alternatives such as natural gas, electricity, and biofuels before, and they are still using them in increasing amounts (6).

Yamık et al. (2013) (7) investigated the effects of JP-8 aviation fuel and diesel blends on exhaust emissions in a single-cylinder diesel engine. In the study, it was stated that towards the end of the 1980s, NATO countries determined JP-8 fuel as a common military fuel, thus ensuring standardization in the fuel used; It was emphasized that 99.8% of JP-8 fuel consists of kerosene so that the freezing point is below -40 °C. In the study; JP-8 was mixed at 5%, 10%, 25%, and 50% and experiments were conducted. As a result, it was observed that engine torque decreased, specific fuel consumption increased (may be due to low density and low cetane number), NOx value decreased and CO value increased as JP-8 addition to diesel fuel increased (8).

In their study on the use of alternative fuels in aviation, Yılmaz and Atmanlı (2016) (7) stated that biofuels have the greatest potential as an alternative to aviation fuels. They stated that biofuels mean less environmental pollution and economic gain compared to fossil-based fuels. In the study, which draws attention to the fact that the International Airline Transport Association (IATA) and the International Civil Aviation Organization (ICAO) support the use of alternative fuels in aviation, they mentioned the necessity of determining important properties such as flash point, octane number and freezing point of the fuel to be used in commercial flights for flight safety. They also emphasized that the alternative fuel to be produced should provide positive results in terms of the raw material from which it will be obtained, the production process, the storage of the fuel, the compliance of its properties with standards, and its transportation. They stated that the biggest obstacle to the use of alcohol as an alternative fuel is the low calorific value and rapid evaporation feature, but in light of technological developments, the chemical properties of alcohols can be changed in the desired direction. As a result, they pointed out that the establishment of new industries for the production of alternative fuels is costly and laborious due to the aviation sector, but they stated that the alternative fuels obtained in the current way can be developed and made compatible with the aviation sector (7).

In an experimental study of the effects of JP-8 Aviation Fuel, Sunflower Oil Metyhl Ester, and Diesel Fuel Blends On Combustion and Engine Performance, experimentally investigated the effects of JP-8, sunflower oil methyl ester, and diesel fuel blends (B25, B50, B75, B100, J100, Diesel) on combustion and engine performance. However, cylinder pressure close to diesel was obtained with B100 and J100 fuels. It was observed that as the biodiesel ratio increased, the KA10 value increased and the combustion tme decreased. The maximum combustion time was determined as 99 and 97.92 °KA with diesel and J100 fuels, respectively. The maximum pressure increase rate was determined as 6.13 bar/°KA with J100 fuel. Compared to the other test fuels, it was observed that the values of indicated average effective pressure and in-cylinder temperature decreased with diesel. As a result, they stated that JP-8 and biodiesel fuel blends can be used in diesel engines without any modification (9).

1.1. Advantages of Biofuel

- It reduces dependence on petroleum products by creating an alternative to these products.
- It reduces the import expenses of oil-deprived countries and makes a positive contribution to their foreign trade balance.
- It significantly reduces greenhouse gas emissions, carbon monoxide, and particulates.
- Additionally, biofuel significantly increases vehicle performance.

• The lubricating effect of biodiesel extends the life of the vehicle engine.
• Raw material producers, from which biodiesel is produced, have a positive impact on the development of rural areas.
• It increases the income of the local people by opening new job areas.
• The development of the biofuel sector will increase economic development by creating new sub-sectors.
• Biofuel is a renewable energy, so biodiesel and ethanol do not leave any harmful waste to the environment after burning.
• It is easier to store biofuel than other alternative fuels because the existing infrastructure is suitable for it.
• Biofuel will also play a positive role in climate change policies. This is especially important for developing countries (10-16).

1.2. Use of Biofuel in Aviation

The greenhouse gas (GHG) emissions from aviation have been growing steadily in recent decades and this trend is set to continue (17). This is primarily due to the rise in international tourism, where air travel represents the mainstay of tourist demand for transportation between the source and host regions (18). Being the major driver of air travel, tourism makes a substantial economic contribution to the global and national economies. Geographically, 'traditional' or 'established' destinations in Western Europe and North America are forecast to retain their strategic importance in terms of tourist demand. Concurrently, the rapid acceleration of tourist flows is envisaged in so-called 'emerging' destinations, such as those in East-Central Europe and Asia. Given that tourism growth correlates with air travel, these 'new' tourist markets are likely to contribute significantly to the continued rise of GHG emissions due to aviation (19). Aviation biofuel is technically viable and nearing the commercial stage. In the last ten years, biofuels have moved from relative obscurity to a point where certain types of fuel have become fully certified for commercial use in up to 50% blends with standard jet fuel and commercial partnerships between airlines and biofuel producers are being established. The need to develop commercially viable alternatives to traditional fossil-based liquid fuels for commercial aircraft is intensifying. The rising price of crude oil, potential new carbon emissions legislation, the negative environmental externality effects resulting from fossil-fuel consumption (including, but not limited to, atmospheric pollution and anthropogenic climate change), and growing global demand for air travel have collectively motivated research into sustainable fuel alternatives (20). Aviation is the transport type that is showing significant, steady, and quite rapid growth in the EU. The international aviation segment accounts for 12.8% of the energy consumed, whereas domestic aviation uses only 1.54% of the energy (21). Air transport is the most growing transportation sector, and it is expected to increase steadily by the year 2030. International Air Transport Association approximates that the industry will have grown by over 5% annually by the year 2030. It is also estimated that the demand for aviation fuels is to grow at 2 to 3% every year. Various studies have proved that the aviation fuel used in the past has several negative effects on the environment and with the increasing usage, the situation is said to be affected the most, which has led to various research to establish other sources of energy that will have little effect on the environment. Researchers have settled on biofuels since they contain more energy, are cheaper, leave a less negative impact on the environment, and have less damage on the engine (22). Combustion of fossil fuels and human activities disturb the environment by the emission of greenhouse gases like nitrous oxide, carbon dioxide, methane, etc. The requirement of oils for transport is growing day by day and it is expected to increase by 1.3% per year up to 2030 (2). There is no unique solution available for these complications so alternative ways such as modification in vehicle designs, development in public transport, and replacement of conventional fuels with alternative advanced fuels and fuel technologies are to be found. It is expected that by 2030, the carbon emission from the transport sector and the energy requirement will have increased up to 80%. Air transport has played a significant role in the everyday life of the modern world. The influence of air travel increased worldwide social contact, especially in improving business and marketing (23).

With the use of biofuel in the aviation industry, an alternative to petroleum-based fuels will be created. The 2% contribution of the airline transportation sector to global carbon dioxide emissions will be reduced to lower levels. In addition, its use and dissemination will be faster and easier than in other transportation sectors (3). The aviation industry continues its efforts to produce the most high-performance fuel at the lowest cost and with the lowest environmental impact (24). Food and water, which are the sources of human life, cannot be used for aviation biofuel. Features required for the raw material required to produce aviation biofuel are as follows: It should grow quickly, should not use the areas used for food production, should not be used as food, should not require large amounts of pesticides, fertilizers, or irrigation, should provide a socioeconomic contribution to the people of the region where it is grown, and lastly, should provide the same or more energy than petroleum-derived fuels, while providing less or even zero carbon footprints (25). Biofuel testing is a must to determine whether that biofuel is suitable for use in aviation. As in every part of the aviation industry, there are very strict standards and safety rules when it comes to biofuel testing. This means that before the use of biofuels, dozens of research and tests were carried out both on the ground and in the air. As a result of these long and tiring studies and tests, it is put into use if the suitability of that biofuel is assured. Safety is the most fundamental criterion in aviation. In an environment, where even conventional petroleum-based fuels are put to the test, the testing criteria for biofuels are even more stringent. After the tests in the laboratory environment, the performance of the aircraft from its movement on the ground to its take-off speed is tested in ground tests. In the meantime, the time between the fuel being taken into the engine and its combustion is measured, and the combustion performance inside the engine, and its reactions to acceleration and deceleration are also measured. After the laboratory and ground tests are completed, the flight performance of the fuel is tested. Many airlines dedicate their planes to testing. Thus, they can provide information on fuel quality, ensure that it is certified for use in the aviation industry, demonstrate that biofuel is safe to use in real flight, and encourage biofuel research and development. During flight, the pilot tests fuel performance both in normal operation and in extreme conditions. After completing the flight checks, the next stage is the certification stage. Certification of the fuel for commercial use is the responsibility of the authorized approval bodies of the relevant countries. The aviation industry works in cooperation with authorized test and approval organizations (26). As the production technology and thus production of sustainable biofuel increases, it will be economically viable and will reach a level that can cope with petroleum-based fuels. Production of biofuel raw materials, especially in developing countries, will contribute to the economic development of both the region and the country (27). Due to the zero carbon emission of biofuel, governments' tax reductions and incentives will increase its production and use. In many countries, research is focused on many different sources (bacteria and solid waste materials) for cheaper and improved biofuels. However, some infrastructure investments are needed to develop and expand the use of biofuel. Such as sufficient raw material production and the need for a refinery to convert this raw material stock into biofuel (28). The aviation industry around the world consumes 1.5-1.7 billion barrels of conventional Jet A1 fuel. Analysts state that it would be possible to say that biofuel production would be economically meaningful if even 1% of this amount was switched to biofuel (15).

2. MATERIALS AND METHOD

2.1. Fuel and Additives Used

The JP-8 fuel we used in the study was obtained from Petrol Ofisi company by obtaining the necessary permissions. The additives used in the study were purchased from various commercial companies. Before the experimental studies, fuel and additive mixtures were prepared and made ready to be used in the test equipment. All of the test studies were carried out in Batman University Technical Sciences Vocational School, Department of Chemistry and Chemical Processing Technologies Fuel Analysis Laboratories.

2.1.1. Jet fuel

JP-8, widely used in the aviation industry and known as jet fuel, was accepted as military fuel by NATO countries in the 1980s. When its chemical structure is examined, this fuel, which consists of 99.8% kerosene, is a fuel obtained by distilling petroleum between 150-270 °C, which is frequently used in industry (29). One of the most important features of this fuel is that its freezing point is below -40 °C. Today, the most commonly used aviation fuels are JET A1, JP-8, JP-4. While others are mostly used in civil aviation, JP-8 is used in military aviation because it provides the standard and prevents high expenditures (30). Kerosene, which constitutes a large portion of 99.8% of JP-8 fuel, generally contains the following hydrocarbons in its structure, with some differences depending on the production process: Aromatics (20%), kinds of paraffin and iso-paraffins (60%), cyclo-paraffins (20%).

Kerosene is a colorless, oily, rapidly flammable, and pungent liquid produced by distilling petroleum (10-25% of the total volume). It is a mixture of 10 different types of simple hydrocarbons obtained from different sources. The carbon chain mixture obtained as a result of fractional distillation generally contains between 6 and 16 carbon atoms per molecule. It is less volatile than gasoline and boils at temperatures between 150 and 275 °C. It is generally burned in lamps, heaters, and stoves, and is also used as fuel or as a fuel component in diesel and tractor engines. It is also used as a solvent in jet engines, rockets, and greases or as an herbicide (insecticide). Kerosene is sometimes used as an additive in diesel fuels to prevent gelation and waxing that may occur in low-temperature operations. Paraffin in the structure of gasoline, diesel, and kerosene obtained from petroleum cannot be used in aircraft because it reduces fluidity at low temperatures. In addition to its high flammability, kerosene is widely used as fuel in jet engines because it maintains its fluidity at low temperatures (31). Kerosene is released by the fine distillation of petroleum between 150-270 °C. The freezing point of kerosene, which has a flash point of 40 °C, is between -47 °C and -49 °C. The most commonly used fuel types containing kerosene in jet fuels are; JET-A, JET-A1, JET-B, JP-4, JP-5, and JP-8 (28) According to an oil report by EMRA, 4.786 million tons of jet fuel was produced in Turkey in 2018. The most commonly used fuel types containing kerosene in jet fuels are JET-A, JET-A1, JET-B, JP-4, JP-5, and JP-8 (32).

JP-8 is a kerosene-based jet fuel developed by the United States in 1990. This fuel replaced JP-4 fuel by the US Air Force in the fall of 1996, as it is a lower flammable, less harmful fuel, safer, and has better combat survivability. The US Navy also uses JP-5 fuel of a similar formulation. This fuel was first used in NATO bases in 1978. Its NATO code is F-34. The flash point of JP-8 is 38 °C, which is higher and safer than the -18 °C flash point of JP-4. JP-5 has an even higher flash point (>60 °C) but is also costly. In addition to fueling aircraft, JP-8 (or JP-5) is used as a fuel for heaters, furnaces, and gas tanks, as a substitute for diesel gasoline in the engines of almost all tactical ground vehicles by the US military forces, and as a coolant in electric generators and in some aircraft components. The use of a single type of fuel greatly simplifies logistics (8). Figure 1 was also developed by ALS for the quantitative analysis of non-volatile hydrocarbons in the C10-C40 range after non-polar solvent (hexane) extraction. The extract is analyzed by a gas chromatograph (GC) with a flame ionization detector (FID).

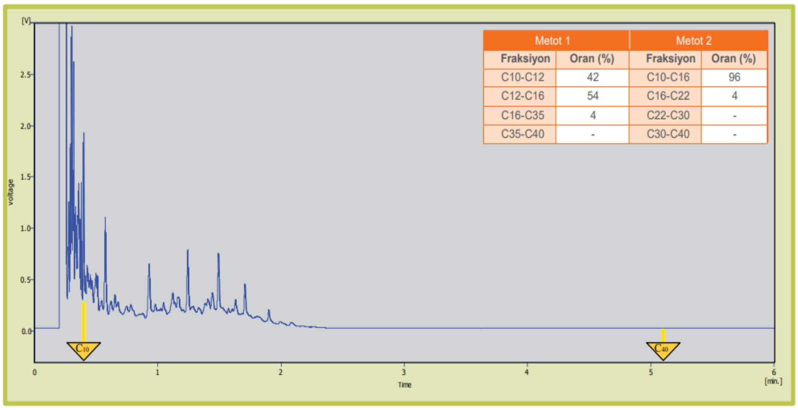

Figure 1[1]: JP-8 Gasoline carbon range analysis by Chromatographic Method GC/FID (33).

Table 1 shows the chemical and physical properties and test methods of JP-8. In addition to this information, we examined the basic chemical and physical properties of JP-8 fuel in the laboratory environment before using it in experiments. JP-8 is a kerosene-type aviation fuel containing a military fuel additive package: Static Dissipative Additive (SDA), Lubricity Improver Additive (LIA) (formerly referred to as anti-corrosion/lubricity enhancer additive), and Fuel System Anti-Icing (FSII-3) and Antioxidant (AO) and Metal Deactivator Additive (MDA). F-34 is used by land-based military gas turbine-powered ground vehicles and equipment in all NATO countries. It is also known as F-34, JP-8, or AVTUR/FSII (32). Table1. and Table 2. "References and technical approval processes of fuels defined according to ASTM" and "Compositional Data for JP-8" are given respectively.

Table 1: Chemical and Physical properties and test methods of JP-8 (34).

Specifications	**Unit**	**Min**	**Max**	**ASTM or IP Test Method**
Color				D156 or D6045
Total number of acids	(mg KOH/g)		0.015	D3242
aromatics	v/v		25.0	D1319
Sulfur	w/w%		0.30	D129, D1266, D2622, D3120
Sulfur, mercaptan	w/w%		0.002	D3227
Flash point	°C	38		D56, D93 , D3828
Density (at 15 °C)	kg/L	0.775	0.840	D1298, D4052
API (at 60 °F)		37.0	51.0	D1298, D4052
Freezing point	°C		-47	D2386 , D5972, D7153
Viscosity (at -20 °C)	mm^2/s		8.0	D445 or D7042
Net heat of combustion	MJ/kg	42.8		D3338, D4529
Hydrogen content	w/w%	13.4		D3343, D3701, D5291
Smoke point	mm	25.0		D1322
Corrosion				
Copper strip corrosion, 2 hours at 100 °C (212 °F)			No. 1	D130
THERMAL STABILITY				
Thermal stability (2.5 hours at 260 °C) 10				D3241
Change in pressure drop, mm Hg			25	
Tube rating: One of the following requirements must be met: (1) Annex A1 VTR or (2) Annex A3 ETR or Annex A2 ITR, mean deposit thickness, nm, over 2.5 mm^2 area			<3	
ADDITIVES				
Fuel system anti-icing, volume percentage		0.07	0.10	D5006
Fuel electrical conductivity, pS/m 12				D2624

[1] Note: Metot is Method, Fraksiyon is Fraction, Oran is Ratio in the figure.

CONTAMINANTS		
Current gum, mg/100 mL 13	7	D381 or IP 540
Water reaction interface degree	1b	D1094
Microseparometer Degree 14		D3948 or D7224

Table 2: Compositional Data for JP-8 (35).

Compound	Weight (%)
Alkenes	
Tridecene	0.73
Alkyl aromatic	
m-Xylene	0.060
o-Xylene	0.060
1,2,3-Trimethylbenzene	0.27
1,2,3,4-Tetramethylbenzene	1.1
1,3-Dimethyl-5-ethylbenzene	0.62
1-Methyl-2-isopropylbenzene	0.56
1,2,4-Triethylbenzene	0.99
1,3,5-Triethylbenzene	0.60
n-Heptylbenzene	0.25
n-Octylbenzene	0.61
1-Ethylpropylbenzene	0.99
Branched paraffin	
3-Methyloctane	0.040
2,4,6-Trimethylheptane	0.070
2-Methyldecane	0.41
2,6-Dimethyldecane	0.66
2-Methylundecane	1.2
2,6-Dimethylundecane	2.1
Naphthenes	
1,1,3- Trimethylcyclohexane	0.060
1,3,5-Trimethylcyclohexane	0.060
1-Methyl-4-ethylcyclohexane	0.10
Propylcyclohexane	0.14
n-Butylcyclohexane	0.74
Hexylxyxlohexane	0.93
Phenylcyclohexane	0.87
heptylcyclohexane	1.0
Diaromatics excluding naphthalenes	
Biphenyl	0.63
n-Paraffins	
n-Heptane	0.030
n-Octane	0.090
n-Nonane	0.31
n-Decane	1.3
n-Undecane	4.1
n-Dodecane	4.7
n-Tridecane	4.4
n-Tetradecane	3.0
n-Pentadecane	1.6
n-Hexadecane	0.45
n-Heptadecane	0.080
n-Octadecane	0.020
Napthalenes	
Napthalene	1.1
1-Methylnapthalene	1.8
2-Methylnapthalene	1.5
1-Ethylnaphthalene	0.33
2,3-Dimethylnaphthalene	0.36
2,6-Dimethylnaphthalene	1.3

2.1.2. Methanol

The use of alcohol as an alternative to fuel has a long history. However, the cost of production processes has hindered their widespread adoption. Increasing oil prices have allowed alcohol to become widespread in recent years. Methyl alcohol was used as an active ingredient in this research due to its potential to be used in many fuel studies and to ensure its continuity in our country (36). Technical properties of methanol are given in Table 3.

Table 3: Technical Properties of Methanol.

Specifications	Explanations
Chemical Name	Methanol
Chemical Formula	CH_3OH
Appearance	Clear Liquid
Molar Mass	32.04 g/mol
Melting point	-97.6 °C
Cas Number	67-56-1
Density	792 kg/m^3

2.1.3. Ethanol

Thanks to the high octane number of alcohols, allows them to be used even at high compression ratios (37). Ethyl alcohol, due to its structure, has the feature of increasing engine performance while reducing emissions when used as fuel. In this study, we wanted to see what effect ethyl alcohol could have on jet fuel. Technical properties of ethanol are given in Table 4.

Table 4: Technical Properties of Ethanol.

Specifications	Explanations
Chemical Name	Ethanol
Chemical Formula	C_2H_5OH
Appearance	Colorless Liquid
Molar Mass	46.07 g/mol
Melting Point	-114.1 °C
Cas Number	64-17-1
Density	789 kg/m^3

2.1.4. Isopropanol

This type of alcohol, known by names such as isopropyl alcohol, and IPA, is similar to ethyl alcohol in terms of its structure and is used more as a solvent in industry. We used this type of alcohol as an additive substance in our study because it can be dissolved well with fuels in any ratio and has a strong oxidizing effect. The technical characteristics of isopropanol are given in Table 5.

Table 5: Isopropanol Technical Characteristics.

Specifications	Explanations
Chemical Name	*Isopropanol*
Chemical Formula	C_3H_8O
Appearance	Colorless Liquid
Molar Mass	60.1 g/mol
Boiling Point	82.5 °C
Cas Number	67-63-0
Density	786 kg/m^3

*2.1.5. Anti-Icing (diethylene glycol monomethyl ether (*di-EGME*)*

In the chemical and dyeing industries, nitrocellulose is used as a solvent for resins and solvents. Purified di-EGME (>99%) is also used as a solvent in cosmetic and dermatological preparations. Di-EGME increases percutaneous absorption through the skin in some pharmaceutical products and it is used in pharmaceutical products in Turkey. Di-EGME is used in shampoos (rinse) at a concentration of up to 5% and conditioners (leave-in) at a concentration of up to 2%, in toiletries, skincare, hair care, or sun care products. It should not be used in products for oral hygiene.

Being a colorless liquid, its use as a solvent for dyes, nitrocellulose, decoctions, and resins stands out among the applications of di-EGME. It is a component of twisting, and conditioning yarns and wood dyes in textile printing products, textile soaps, lacquers, penetration enhancers in cosmetics, drying lacquers, enamels, and brake fluids. Mineral oil soap is used as a neutral solvent in mineral oil-sulfated oil mixtures (by giving fine dispersions in water) and for determining the saponification values of oils. Di-EGME is a very polar, slow-evaporating, water-miscible, odorless solvent. It is an active solvent for cellulose acetate, nitrocellulose, epoxy resins, and many other coating materials. Although diethylene glycol methanomethyl ether is a flammable liquid, it is stable under the recommended conditions. Storage containers made of carbon steel, stainless steel, or phenolic-lined steel are recommended for storage and preservation. It should also be avoided from contact with strong acids, strong bases, and strong oxidizers. Diethylene glycol monomethyl ether should not be distilled until it is completely dry because it can form unstable peroxides. Diethylene glycol monomethyl ether can be oxidized at high temperatures. Thermal decomposition products may include, yet are not limited to: aldehydes, ketones, and organic acids. The pouring of glycol ethers, including di-EGME, on hot fibrous insulation can lead to a decrease in self-ignition temperatures and possibly spontaneous combustion since it is a flammable liquid and stable under the recommended conditions. The technical characteristics of dietary glycol monomethyl ether are given in Table 6.

Table 6: Technical Characteristics of Diethylene Glycol Monomethyl Ether.

Specifications	Explanations
Chemical Name	Diethylene Glycol Monomethyl Ether
Chemical Formula	$C_5H_{12}O_3$
Appearance	Colorless Liquid
Molar Mass	120.148 g/mol
Boiling Point	194 °C
Cas Number	111-77-3
Density	1020 kg/m^3
Freezing Point	-69 °C

2.2. The Effects of Additives Used in the Study on Fuel Properties

In this study, additives such as methanol, ethanol, isopropanol, and anti-icing were added to jet fuel (JP-8) in the proportions of 2%, 5%, 7%, and 10% and the fuel properties such as density, viscosity, flash point and freezing point of the obtained mixtures were examined. In Table 7, the cumulative results of all experiments with additives added to JP-8 fuel are given. In addition to the results of the pure states of the fuel and additives, the results of the effects of each of the additives added to the jet fuel in the specified proportions on the fuel properties are also seen in the table.

Table 7: Fuel properties of JP-8 and additives used in the study.

(%)	Fuels / Properties	Density 15 °C (kg/m^3)	Kinematic Viscosity 40 °C(mm^2/s)	Flash Point (°C)	Freezing Point (°C)
Pure	Jet fuel (JP-8)	797.0	1.198	46.0	-56.7
	Methanol	793.0	0.597	12.0	-97.8
	Ethanol	795.0	1.102	13.0	-114.1
	isopropanol	789.0	1.768	11.7	-89.0
	Anti-Icing	1020	3.680	96.0	-69.0
2%	Methanol	796.8	1.156	45.3	-56.9
	Ethanol	796.9	1.160	45.5	-58.6
	isopropanol	796.1	1.201	45.0	-56.2
	Anti-Icing	799.8	1.410	47.4	-56.3
5%	Methanol	796.5	1.144	43.9	-57.9
	Ethanol	796.7	1.140	44.6	-59.2
	isopropanol	795.6	1.255	44.4	-56.8

	Anti-Icing	803.4	1.530	50.1	-55.8
7%	Methanol	796.1	1.126	42.0	-59.8
	Ethanol	796.5	1.138	44.0	-60.8
	isopropanol	795.0	1.270	43.7	-57.0
	Anti-Icing	808.6	1.750	53.3	-55.1
10%	Methanol	795.5	1.109	40.0	-61.7
	Ethanol	796.2	1.130	43.4	-62.1
	isopropanol	794.4	1.298	42.9	-57.6
	Anti-Icing	814.5	1.980	55.4	-54.6

2.2.1. Density Change

Density is an important quality parameter for gasoline, diesel jet fuel, and all other fuels. It is used to define the product and determine other characteristics. A high density also means that for international product trade, it means the transport of more energy in a low volume. Density (also known as specific gravity) is an indicator of the amount of weight that falls per unit volume of fuel. Density is a basic parameter for all fuels. As the density increases, the amount of energy per unit volume also increases. Since the energy contained by each hydrocarbon in the fuel is different, the types and quantities of components in the jet fuel mixture are very important. Since the density of a fuel is a manifestation of the chemical structure of its composition, it also has the property of being an indicator of its energy value. In general, when looking at fuels with a low density, it is seen that their gravimetric energy content is high, and those with a high density have an excess of volumetric energy content. Fuels with high volumetric energy, that is, excess density, are preferred in aircraft. Because the volumetric energy per unit volume is greater, the aircraft can travel longer distances with a tank of fuel. As shown in Figure 6, the density of pure JP-8 is higher than pure methanol, ethanol, and isopropanol; and since the mentioned alcohols are added to JP-8 in the specified proportions, it appears that there is a partial, if not a lot, decrease in the density of the resulting fuel mixture. However, since the density of the anti-icing additive used in the study is much higher than JP-8, it has been found that there is a relative increase in the density of the fuel mixtures obtained when JP-8 is added in the specified proportions. This means that if the fuel is injected into the engine at a constant rate, the energy supplied to the engine increases with intensity and thus the engine performance will increase. On the other hand, it can be said that as the density decreases, volumetric fuel consumption will increase due to the above-mentioned reasons.

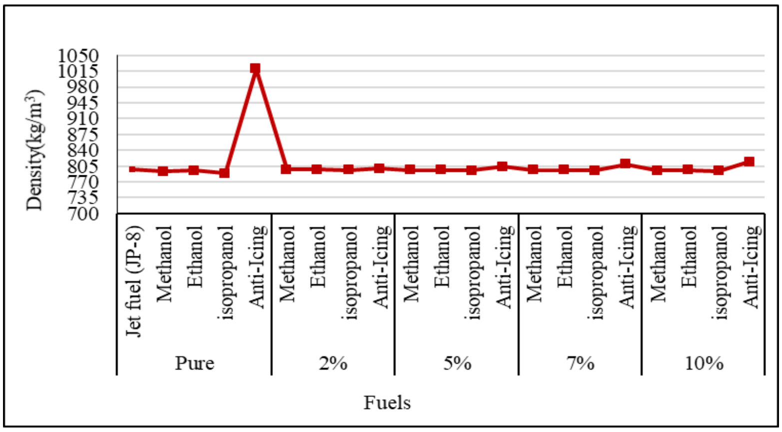

Figure 6: Changes in the density of additives used in pure form and the specified proportions.

2.2.1. Viscosity Change

Viscosity is the resistance of a liquid or gaseous fluid to flow. In other words, it is called the resistance that a liquid or gaseous fluid exhibits to the displacement of a part relative to a part next to it. Viscosity, translated into our language as fluidity, can also be considered as the deceleration force between molecules since the part forced into motion for a fluid will also drag its adjacent parts with it. Such a force prevents the formation of velocity differences in the fluid. For fluids to be transmitted from one place to another by pipelines or to be used as a lubricating material, viscosity is one of the most important factors in determining the forces that resist the flow. In addition, viscosity is used in the regulation of liquid flow in processes such as" spray casting, spraying, and surface coating". As a result of increasing temperature, the viscosity of liquids decreases, while the viscosity of gases increases rapidly. Therefore, when liquids are heated, liquids flow more easily, but gases are more difficult. Along with this, as the fuel viscosity decreases, it will cause a significant power loss, as there will not be enough fuel supply in the engine as a result of leaks. The high viscosity of the fuel may cause the injection pump not to provide enough fuel to fill the fuel chamber. Failure to provide enough fuel will again cause a loss of power in the engine. Jet fuel should be able to flow easily from the fuel tank located on the wings of the aircraft to the engines through the aircraft fuel system. As the temperature drops as the altitude increases, the fuel in the aircraft's tanks cools down, in the same way that the fuel in the tanks on the ground faces the risk of freezing during the winter seasons. Under all conditions, jet fuel should maintain its fluidity, it must not freeze, that is, not become viscous. Because the viscosity and freezing points of kerosene-type jet fuels are higher than those of wide-cut jet fuels, they are less suitable for cold climatic conditions. One of the physical properties of jet fuel is the freezing point and viscosity, which are important criteria for its fluidity. Jet fuel is injected into the combustion section of the turbine engine through nozzles. The system sprays the fuel droplets into a fine spray, allowing them to mix with air, while also triggering their immediate evaporation. The size and shape of the droplets in question are related to the viscosity of the fuel. If the viscosity of the fuel is higher than the required value, the engine is forced while taking off. This causes the pressure to drop in the fuel system lines and the fuel pump to operate with excess power to maintain a constant fuel flow rate. For these reasons, the viscosity is limited to the maximum values in the specifications (38). Too high viscosity prevents the jet fuel from being atomized sufficiently. Aircraft engine fuel systems, fuel lines, valves, and pumps are of minimum size and weight and are designed to operate with liquid fuels within a specific viscosity range. Since the viscosity of jet fuels depends largely on temperature, the viscosity of the fuel at the minimum operating temperature should be known. In addition, the effect of viscosity on fuel atomization is important. The performance of pressurized sprayers and air-assisted sprayers largely depends on the fuel viscosity. The subsequent evaporation of the fuel and mixing of the fuel with air to form a flammable mixture depends greatly on the performance of the fuel nozzle. Engine manufacturers specify a maximum fuel viscosity of 12 centistokes for reliable engine start-up performance, which will limit engine start-up to temperatures of -20 to-30 °C when using JP-5, JP-8, Jet A, or Jet A-1 kerosene fuels. Kinematic viscosity is determined by measuring the time it takes for a fixed volume of fuel to flow through a calibrated capillary tube at a predetermined temperature. The viscosity is calculated from the flow time and the capillary tube diameter and length. In the 1940s and 1950s, the standard viscosity test temperature was -40 °C, but in recent years, international standardization agencies have decided on a -4 °C test temperature. The standard viscosity test method is ASTM D 445, Transparent and Ovaaue Kinematic Viscosity (39). Figure 7 shows the kinematic viscosity (1.198 mm^2/s) of JP-8 used in the study is higher compared to methanol and ethanol used as additives (0.597 and 1.102 mm^2/s, respectively). Therefore, it has been observed that when these alcohols are added to JP-8 in the specified proportions, the viscosities of the fuel mixtures obtained also decrease relatively. This is a fact that fuel can easily flow into the engine due to the low viscosity of the fuel as the aircraft rises higher. The viscosities of the isopropanol and anti-icing additives we used in the study (1,768 and 3,680 mm^2/h, respectively) are higher than JP-8, and it is observed that the values of the mixtures obtained as a result of measurements partially increase when they are added to the fuel at the rates indicated in our experimental studies. It is expected that this situation can be tolerated and that the addition of these additives to the fuel at the specified rates will not create a problem on flights.

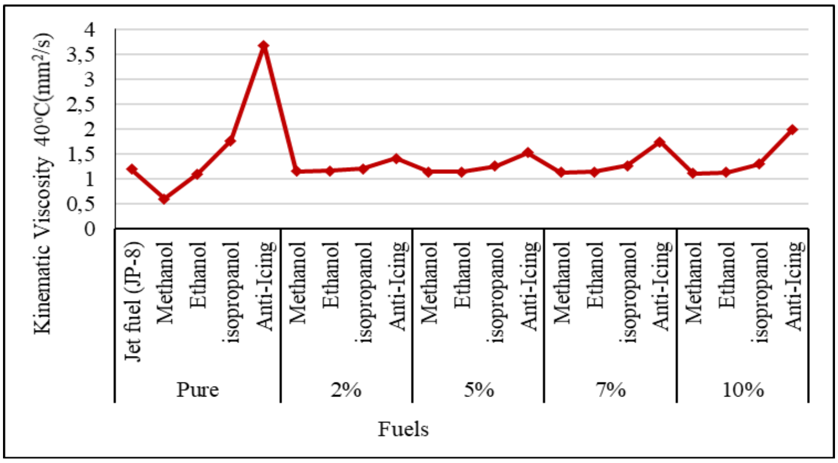

Figure 7: Changes in the kinematic viscosity of additives used in the pure state and the specified proportions.

2.2.1. Flashpoint Exchange

A flash point is the lowest temperature at which a sample of a flammable substance causes its vapor to ignite under certain conditions, according to ASTM. The flash point is one of the most important criteria for determining the hazard of flammable liquids. It can also be called the lowest temperature value that a flammable liquid can produce enough vapor to create a one-second flame. The flash point is often confused with the spontaneous ignition temperature. The flash point is the lowest temperature at which the fuel vapor will continue to burn even after the ignition source has been removed from the environment. The flame point is higher than the flash point, because at the flash point, steam may not be released quickly enough to keep the combustion going. The flash point is not directly related to the ignition source temperature; however, the ignition source temperature is higher than the flash point. Among the flammable fuels, the flash point is a distinctive feature. The flash point is also an important parameter for defining the fire hazards of fuels. Fuels with a flash point of less than 37.8 ° C are defined as flammable, while fuels with a flash point above this temperature are also called flammable fuels. In gas turbines and jet engines, fuels with a higher flash point and at low cost are preferred. It is safer to transport and process such fuels. The flash point of a liquid is defined as the lowest temperature at which it produces enough vapor to create a "vapor/air" mixture that can ignite (pilot ignition). The vapor pressure of the liquid at this temperature ensures a vapor concentration equal to the lower flammability limit. If ignition is attempted when the liquid reaches the flash point, a flare flame will form, but the flame will not continue. The cloud will burn and the fire will go out on its own because the energy released as a result of combustion is transferred to the remaining fuel and is not enough to produce enough steam in the remaining fuel. Since the flash point is the lowest temperature at which there is a risk of fire with a certain liquid, it is an important concept in fire investigation and fire protection. It is very important in many cases to detect the presence of certain liquids during the investigation process and to know the flash points (40). The flash point is very important for fuels with a low carbon content. The JP-8's flash point (36 °C) is quite high and safe compared to the JP-4's flash point (-18 °C). As can be seen in Figure 8, the flash points of methanol (12 °C), ethanol (13 °C), and isopropanol (11.7 °C) are much lower than JP-8. Although the values indicated in the study are not very high when these alcohols are added to JP-8, it is observed that the flash points of the mixtures partially decrease. However, it is thought that this amount of decrease will not pose any problems in the transportation and processing of fuel. Since the flash point (96 °C) of the anti-icing additive we used in the study is much higher than JP-8, the flash points of the mixtures were measured as 47.4 °C, 50.1 °C, 53.3 °C and 55.4 °C, respectively when 2, 5, 7 and 10% were added to the fuel (JP-8). According to these obtained values, it is seen that the transportation and use of fuel mixtures have reached a more reliable point.

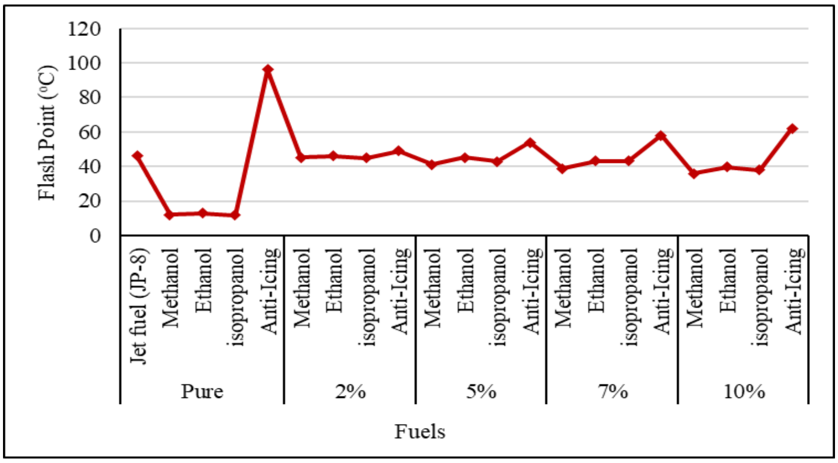

Figure 8: Changes in the flash point of additives used in pure form and the specified proportions

2.2.1. Freezing Point Change

The freezing point in jet fuels is defined as the temperature at which the last wax crystals contained in the test sample, which are cooled until wax crystals are formed, also melt when heated. In this case, the freezing point is a higher temperature than the solidification point of the fuel. One of the most important features of a fuel system is the performance of pumping the fuel contained in the tanks into the engine. The ability of the pump-to-pump fuel also depends on the fluidity of the fuel and the design of the system. When conducting tests related to fuels, the freezing point of the fuel is taken as the criterion for pumping at a low temperature. Jet fuels can be pumped even at temperatures 4ºC-15 ºC lower than the freezing point. It is the ability of the fuel to be used in cold weather. Fuel molecules that cool down to a certain temperature crystallize, and freeze when the temperature drops further. Crystallized fuel blocks the fuel system, preventing the flow of fuel. For these eight reasons, the freezing point of fuels should be between 5 and -10 °C lower than the outside air temperature of the region. The freezing point is very important for the transfer of fuel from the tank to the engine while the engine is cold and during the first movement (41). Although there is no direct relationship between the freezing point and the viscosity, the freezing point increases or decreases with the viscosity. The high freezing point causes initial movement difficulties if the heating of the fuel is excluded. During the operation of the engines at temperatures near the freezing point, the fuel filters become clogged. Therefore, the required freezing point depends on the lowest operating temperature of the machine (42). As can be seen in Figure 9, the freezing points of the alcohols and anti-icing we used in the study are much lower than JP-8. Therefore, it has been found that when these additives are added to JP-8 at the specified rates (2, 5, 7, and 10%), the freezing points of the new fuels obtained gradually decrease. It is also believed that problems such as fuel freezing cannot occur by increasing the altitude of aircraft in this situation.

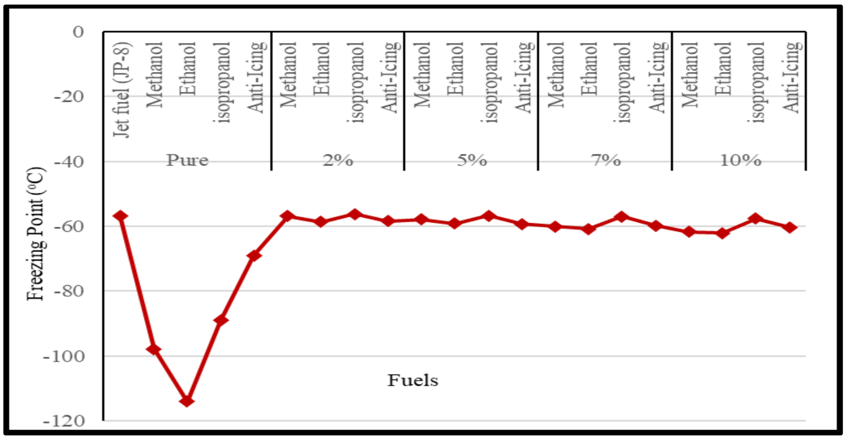

Figure 9: Changes in the freezing point of additives used in the pure state and the specified proportions.

3. DISCUSSION

1. Like many countries in the world, our country is a country with very low reserves in terms of fossil fuels. This situation leads to the export of domestic capital along with its dependence on foreign energy.

2. With its growing population, Turkey has become an important center in Europe, Central Asia, and the Middle East in the industry and defense industry, especially in the energy field.

3. In recent years, our country has reached a very important point in the production and use of renewable energy sources. According to the data for the last quarter of 2021, 55% of the total energy production was produced from domestic and renewable energy sources.

4. The importance of biofuels among renewable energy sources is quite high. In this sense, the importance of fuels such as bioethanol, biomethanol, biodiesel, bioisopropanol, biogas, and hydrogen is increasing day by day.

5. Ethanol, methanol, and isopropanol, which are used as additives in this study, can be used as fuel alone, or they can also be used by adding them to some fuels to improve certain properties.

6. The densities of the alcohols (ethanol, methanol, isopropanol) used in the study are lower than JP-8 fuel. When 2%, 5%, 7%, and 10% of these alcohols were added to JP-8 fuel, the densities of the mixtures formed decreased slightly compared to the density of JP-8 fuel. The decrease in the density of the fuel with the addition of these alcohols will also lead to a decrease in energy values. However, it is thought that this small amount of energy decrease that will occur will be at a tolerable level. In addition, apart from the above-mentioned alcohols, the density of the anti-icing agent added to the fuel is much higher compared to JP-8 fuel and pulls the density of the mixture up with an increase in the additional ratio. In this case, it is expected that the energy value of the fuel mixture will increase.

7. In particular, the viscosities of the fuels used in aircraft are of great importance. Since the viscosity of the methanol used in the study (0.597 mm^2/s) is low compared to the viscosity of JP-8 fuel, it was also found that the viscosity of the mixture decreases as the proportion of methanol mixed into the fuel increases. In this way, it will be possible for the fuel to flow more easily from the tank to the engine. Since the viscosity value of ethanol is 1.10 and it is very close to our main fuel JP-8 fuel, it has been found that there is no significant change in the viscosity value of the mixture when mixed at 2%, 5%, or 7% and 10% rates. However, since the viscosity values of isopropanol and anti-icing additives (1.768 and 3.680) are very high compared to JP-8 fuel, it has been observed that there is a significant increase in the viscosity of the new blend fuels formed when added to the main fuel at the specified rates in the study. However, it is thought that these increases are at a level that will not pose a problem caused by viscosity during flight.

8. One of the important features of jet fuels is the flash point. Since the flash point values of the alcohols used in the study (12, 13, 11, 7) were much lower than JP-8, fuel, the flash point values of the fuel mixtures obtained when the specified amounts were added to the main fuel decreased relatively. However, it is thought that these reduced amounts will not carry a risk in the transportation and processing of fuel. The flash point (96 °C) value of the anti-icing used as an additive is quite high compared to JP-8. It is observed that the flash point values of fuel mixtures formed when added to the main fuel at the rates indicated in the study also gradually increase. With the increase in the flash point value, the transportation and use of fuel mixtures have become even more reliable.

9. One of the most important features sought in jet fuels is the freezing point of the fuel. The freezing point of JP-8 used in the study is -56.7 °C and is higher than all of the additives used. In this case, it has been observed that the freezing point values of fuel mixtures gradually decrease with additives added to the fuel at the rates of 2%, 5%, 7%, and 10%. Aircraft cruising at very high altitudes are exposed to low temperatures. These low temperatures bring with them the risk of freezing of

fuels. As mentioned above, it is believed that these risks will be reduced thanks to the freezing point, which is significantly reduced by additives added to jet fuel in various proportions.

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