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Stability Analysis of Jet Fuel-Bioethanol Blends: an Experimental Approach

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ABSTRACT - Incorporating bioethanol into jet fuel blends has garnered increasing attention as a viable strategy to reduce dependence on fossil fuels and address environmental issues. This study investigates the influence of different amounts of bioethanol on the stability properties of jet fuel blends. Bioethanol addition to jet fuel causes a steady increase in its freezing point. The alteration has been attributed to the destabilizing effect caused by polar hydrogen bonds in bioethanol on the intermolecular forces. Oxidation stability analysis demonstrates a clear correlation between ethanol content and a swift decrease in pressure resistance. Although pure jet fuel is highly stable, mixes that include bioethanol show much lower stability. This decline highlights the reduced impact of bioethanol on fuel stability and oxidation processes. The simultaneous occurrence of gum formation emphasizes the need for careful formulation strategies to prevent stability problems and system complexities. Moreover, the complex influence of bioethanol on the temperature, stability, and oxidation properties of jet fuel blends highlights the importance of using accurate formulation methodologies to improve aviation fuels.

Keywords: aviation fuels, bioethanol, existent gum, jet fuel, oxidation stability.

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INTRODUCTION

The global energy crisis has significantly increased the focus on alternative energy sources, with Indonesia experiencing this shift intently. Fossil fuels currently supply half of Indonesia's energy requirements across various sectors, including industrial, transportation, and commercial. This heavy dependence has led to a swift depletion of fossil fuel reserves, raising major alternative energies, and sustainability concerns (Abdurrojaq et al. 2022; Aisyah et al. 2016; Fajar et al. 2011) . Consequently, there is an urgent need for Indonesia to explore and develop renewable energy sources to lessen this reliance on fossil fuels (Harijono et al. 2021). Transitioning to renewable energy aims to improve energy security and address the environmental issues linked to fossil fuel consumption.

Globally recognized as Jet A-1, jet fuel is essential for jet aircraft, including jet propulsion and propeller types. This fuel is mainly kerosene-based and is refined to meet strict standards, particularly regarding smoke point, oxidation stability, and freezing points (Kusniawati et al. 2021). These standards are critical to ensuring the safety and efficiency of aviation operations. The environmental impact of burning fossil fuels has driven substantial interest in biofuels like bioethanol, which present a more sustainable alternative (Nikkhah et al. 2020; Sadhukhan et al. 2019). Furthermore, adopting biofuels in aviation has the potential to reduce the sector's carbon footprint and promote cleaner energy practices.

Bioethanol, derived from renewable resources, is widely studied as a fuel additive for its high-octane rating and clean-burning properties. With an octane rating above 100 and a 35% oxygen content, bioethanol ensures stable combustion and significantly lowers carbon monoxide emissions. Its use in road transport has prompted consideration of other alcohols as alternative jet fuels. However, bioethanol's low calorific value reduces the temperature before the turbine, decreasing mechanical work and propulsion force. This leads to increased fuel consumption with higher bioethanol concentrations, showing a 2.52% increase in propulsion force at 15% bioethanol (Chuck & Donnelly 2014a; Xie et al. 2024). Overall, bioethanol's role in fuel decarbonization makes it a key component in reducing greenhouse gas emissions. However, its potential to enhance fuel properties positions bioethanol as a promising alternative to fossil fuels, including jet fuel (Prihandini et al. 2016). Despite its common use in improving gasoline octane ratings and reducing emissions (Pumphrey et al. 2000), research on its incorporation into jet fuel remains limited.

This study aims to fill this research gap by investigating the stability characteristics of jet fuel-bioethanol blends. Specifically, we analyze the effects of different bioethanol concentrations on the oxidation stability of jet fuel. Previous research by Auzani et al. (2021) showed that adding ethanol could alter the induction period of kerosene, indicating significant implications for jet fuel stability. Understanding these effects is crucial, as fuel stability directly impacts the safety and reliability of aviation operations. The main objective of this research is to identify the optimal bioethanol-jet fuel blend composition that maintains fuel stability, defined as the fuel's resistance to oxidation and degradation, which is vital for aviation safety. Therefore, unstable fuel can result in engine malfunctions, higher maintenance costs, and, in extreme cases, engine failure (Jia et al. 2020).

The insights gained from this research will contribute to the broader goal of advancing sustainable energy solutions in the aviation sector. Addressing the environmental impact of fossil fuel consumption, our study supports the transition towards cleaner and more efficient energy sources. Adopting bioethanol in aviation fuels promises to enhance fuel performance and aligns with global efforts to reduce carbon emissions.

METHODOLOGY

Materials

The jet fuel and bioethanol test samples were sourced from Indonesian fuel companies. Table 1 provides a summary of the physicochemical properties of these samples.

Jet Fuel/Bioethanol Fuel Blends Formulation

In this study, pure jet fuel was blended with fuel-grade ethanol at volumetric concentrations of 1% (E1), 2.5% (E2.5), 5% (E5), 10% (E10), and 20% (E20). The E1, E2.5, E5, E10, and E20 refer to the volumetric ethanol concentrations in the jet fuel blends, with E1 containing 1% ethanol, E2.5 containing 2.5% ethanol, and so on. The ethanol was added to jet fuel until the mixture reached a predefined volume, ensuring precise concentration levels for each blend. To ensure proper mixing and due to the volatile and hygroscopic nature of the substances, each sample was shaken for at least one minute in a sealed container to prevent air contact.

Jet Fuel/Bioethanol Blends Properties Measurements

Each test sample underwent analysis shortly after preparation to ensure its integrity and the accuracy of the results. The choice to conduct freezing point, oxidation stability, and existent gum content analyses was based on the critical importance of these properties in evaluating the performance and safety of aviation fuels. Freezing point affects the

Table 1
Properties jet fuel and bioethanol

Properties	**Samples**		**Methods**
	Jet Fuel	**Bioethanol**	
Color	22,0	-	ASTM D156
Appearance	Clear, bright and free of solids particles and water at room temperature	-	
Water content (% v/v)	0,007	0,23	ASTM D6304
Freezing point (^{O}C)	-54,2	-114	ASTM D5972
Density @15°C (kg/m^{3})	799,8	794,9	ASTM D4052
Viscosity @ -20°C (mm^{2}/s)	3,728	-	ASTM D5972
Distillation			ASTM D86
- IBP (^{O}C)	150,8		
- 10% gain (^{O}C)	171,2		
- 50% gain (^{O}C)	196,2	79,3	
- 90% gain (^{O}C)	231,6		
- FBP (^{O}C)	249,1		
- Residue (% v/v)	1,20	0,50	
- Loss (%v/v)	0,80	0,50	
Jet Fuel Thermal Oxidation Test			
- The pressure difference (mm Hg)	0	-	ASTM D3241
- Test tube temperature (^{O}C)	260	-	
- Rating tube	1	-	
Existent gum (mg/100mL)	2,9	<0,5	ASTM D381
Total acid number (mg KOH/g)	0,03	-	ASTM D664
Research octane number (RON)	-	106-115	ASTM D2699
Oxygen (% w/w)	-	35,7	ASTM D4815
Ethanol content (% w/w)	-	99,5	GC
Reid vapor pressure (kPa)	-	20	ASTM D5191

fuel's usability at high altitudes; oxidation stability indicates the fuel's resistance to degradation over time, and gum content impacts the cleanliness and efficiency of the fuel system.

The freezing point was determined following the ASTM D5972 standard method using a Jet Fuel Analyzer for Freezing by Phase Technology. Oxidation stability was assessed using the Anton Paar RapidOXY 100 in accordance with ASTM D7545, which measures the induction period under specific conditions, indicating the oxidation and storage stability of middle distillate fuels. The existent gum content was measured using the ASTM D381 standard test method. It evaluates the gum content of aviation fuels, motor gasoline, and other volatile distillates in their finished form during testing.

RESULT AND DISCUSSION

Base Fuel and Bioethanol Properties

Table 1 presents the physicochemical properties of commercial jet fuel compared to bioethanol. Bioethanol has a similar density to jet fuel, around 795 kg/m^3, but differs significantly in oxygen content (35% by mass) and research octane number (over 105). Additionally, bioethanol has a high water content of 0.23% v/v, necessitating careful consideration in surrogate blends for jet fuel.

Freezing Point

Figure 1 shows the freezing points of jet fuel-bioethanol blends ranging from 5 vol% to 20 vol%. The results indicate a gradual increase in the freezing point with the addition of bioethanol, following a polynomial relationship. Each 1 mL increment of bioethanol raises the freezing point by 1.16°C, with a 93% variation. The highest increase, 14.1°C, was observed at a 5% bioethanol concentration. Although pure bioethanol has a freezing point of -114°C and jet fuel -47°C, their blends exhibit higher freezing points due to non-ideal solid-liquid equilibrium behavior. This is attributed to the formation of positive azeotropes and the disruption of hydrogen bonds by weaker London and van der Waals interactions from jet fuel (Lapuerta et al. 2020).

Bioethanol's polar nature, which can form hydrogen bonds, significantly affects the freezing point of blends. These bonds alter the intermolecular forces, disrupting the molecular arrangement necessary for crystallization and leading to higher freezing points. Higher bioethanol concentrations result in more pronounced hydrogen bonding effects, impacting the freezing behavior of the blends (Chuck & Donnelly 2014b; Lown et al. 2014).

The formation of hydrogen bonds between molecules can lead to changes in the intermolecular forces within the mixture. These intermolecular bonds disrupt the conventional molecular arrangement necessary for crystallization, thereby causing either depression or elevation in the freezing point, contingent upon the strength and extent of hydrogen bonding interactions (Amine et al. 2018; Andersen et al. 2010). The intricate interplay of hydrogen bonding, molecular geometry, and the colligative properties of the blend collectively govern the observed alterations in freezing behavior. Such phenomena find relevance in understanding polar hydrogen bond effects on freezing points in surrogate blends. In higher concentrations of bioethanol, the hydrogen bonds can be formed ideally, and the effect will be less pronounced (Aghahossein Shirazi et al. 2019; Shirazi et al. 2020; Turner et al. 2013).

Oxidation Stability

Oxidation stability, a crucial performance characteristic of jet fuels, was assessed using the ASTM D7545 RSSOT method. Figure 2 shows that pristine jet fuel exhibits the highest oxidation stability, taking approximately 24 hours to achieve a 10% pressure drop. Ethanol, with a lower oxidation stability of less than 6 hours, reduces the stability of jet fuel/bioethanol blends. The E20 blend displayed the lowest stability, requiring only 272 minutes (4.5 hours) for a 10% pressure drop. Meanwhile, according to research by (Auzani et al. 2021), ethanol has a lower oxidation stability value than jet fuel, which is less than 6 hours to achieve a pressure drop of 10%. Consequently, increasing the ethanol concentration in the jet fuel/ bioethanol blends decreased the stability of the fuel. The inclusion of bioethanol introduces polar oxygenated compounds, affecting the fuel's hydrocarbon constituents and oxidation processes.

These interactions influence the oxidation processes and subsequently affect the fuel's stability. Bioethanol's potential role in either enhancing or mitigating oxidation instability depends on factors such as blend composition, ethanol concentration, and synergistic or antagonistic interactions with the fuel matrix (Jia et al. 2021).

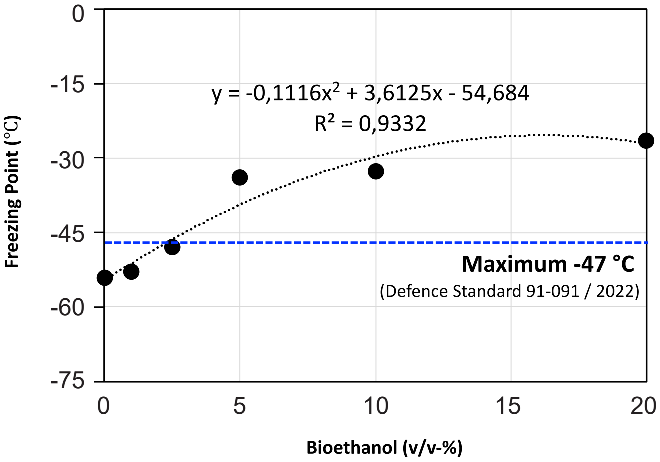

Figure 1
The freezing point of jet fuel/bioethanol blends

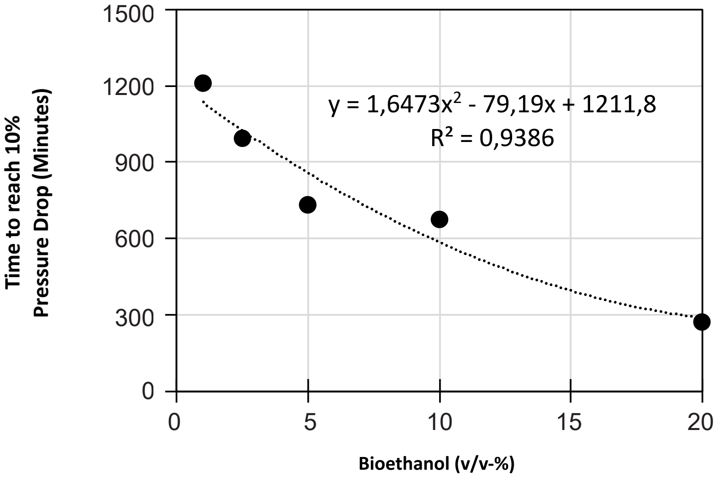

Figure 2
Oxidation stability of jet fuel–bioethanol blends

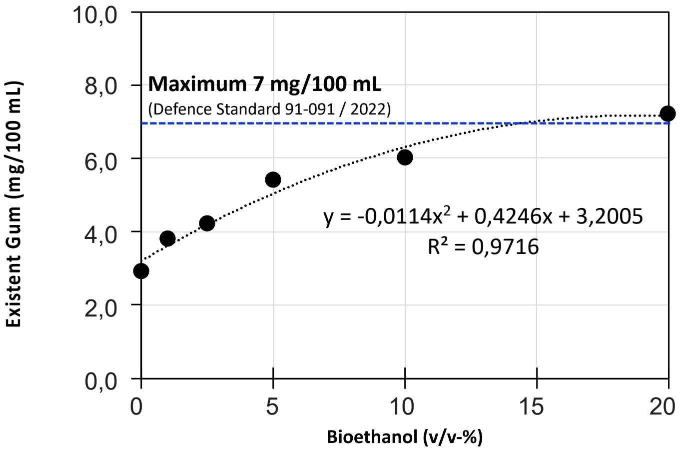

Figure 3
Existent gum of jet fuel–bioethanol blends

Table 2
Stability properties jet fuel and bioethanol blends

Properties	Methods	Pure Jet Fuel	5% blend	20% blend
Freezing point (^{O}C)	ASTM D5972	-54	-32	-28
Existent gum (mg/100mL)	ASTM D381	2.9	5.7	7.2
Time to Pressure Drop 10% (minutes)	ASTM D7545	1200	750	300

Existent gum

The existent gum analysis of jet fuel/bioethanol blends is presented in Figure 3. At first glance, it can be seen that pristine jet fuel has a gum content of about 3 mg/100 mL, whereas the existent gum content for the blends has a linear correlation to ethanol's concentration. Based on the results, a higher amount of ethanol added to jet fuel increases the gum content. When ethanol is added, more gum is formed due to heating during the analysis process (steam) which makes ethanol tend to become unstable and the bonds will be broken. So there will be an oxidation reaction of ethanol to form ethanal compounds (formaldehyde) and ethanoic acid and a polymerization process occurs between the products of ethanol oxidation (Yang et al. 2019).

The gum formed is a non-volatile compound, so it can be estimated that the gum compound formed from the analysis of the jet fuel/bioethanol mixture is an ethanol compound that is more non-volatile than ethanoic acid. This is because the ethanoic acid formation while heating process in which contains stronger hydrogen bonds network which make it easier to polymerization and form gum deposit (Hassan et al. 123 C.E.; Tran et al. 2020).

Table 2 provides a concise overview of how the stability properties of jet fuel are influenced by the incorporation of bioethanol. The freezing point, existent gum content, and time to pressure drop serve as valuable benchmarks for evaluating the performance and suitability of these blends in aviation applications. The 5% blend improves over the 20% blend, suggesting that a higher bioethanol concentration leads to a less favorable freezing point. Furthermore, as the percentage of bioethanol in the blend rises, there is a proportional increase in the potential for gum formation. Additionally, the pure jet fuel has the longest time to a 10% pressure drop, followed by the 5% blend and the 20% blend. This underlines that higher bioethanol concentrations contribute to a more rapid decrease in pressure resistance, highlighting a potential trade-off between bioethanol inclusion and fuel stability.

CONCLUSION

Stability properties aspects of the incorporation of bioethanol in jet fuel blends were comprehensively explored using experimental techniques, including freezing point, oxidation stability, and existent gum content. The freezing point increases significantly at a concentration of 5% bioethanol, reaching a value of 14.1°C. The observed phenomenon can be ascribed to the disruptive properties of polar hydrogen bonds in bioethanol, which affect the intermolecular interactions and consequently modify the freezing properties. Furthermore, the evaluation of oxidation stability showed a clear relationship between the content of ethanol and the faster pace of pressure drop. This measurable decrease highlights the impact of bioethanol on the stability of fuel and the pathways of oxidation. The simultaneous appearance of gum formation in these blends emphasizes the importance of carefully controlling bioethanol-containing formulations to address stability problems and potential system complexities. Overall, these measurable impacts highlight the complex influence of bioethanol on the thermal, stability, and oxidation properties of jet fuel blends. This underscores the need for specific formulation strategies to improve aviation fuel.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
ASTM	American Society for Testing and Materials	
Freezing Point	Temperature at which a liquid change into a solid	^{O}C
Existent Gum	The evaporation residue of aviation fuels, without any further treatment	mg/100 mL
Oxidation Stability	Time to Pressure 10%	minutes
RSSOT	Rapid Small Scale Oxidation Test	

REFERENCES

Abdurrojaq, N., Zaelani, R., Haley, B.A., Fathurrahman, N.A., Anggarani, R., Wibowo, C. S. & Maymuchar, 2022, The Effect of Methanol-Gasoline (M20) and Ethanol-Gasoline (E20) Blends on Material Compatibility. Scientific Contributions Oil and Gas, 45(2), 87–94. https://doi.org/10.29017/SCOG.45.2.966.

Aghahossein Shirazi, S., Abdollahipoor, B., Martinson, J., Windom, B., Foust, T. D., & Reardon, K. F., 2019, Effects of dual-alcohol gasoline blends on physiochemical properties and volatility behavior. Fuel, 252(April), 542–552. https://doi.org/10.1016/j.fuel.2019.04.105.

Aisyah, L., Setyo Wibowo, C., Ayu Bethari, S. & Kunci, K., 2016, Comparison Of Biodiesel B-20 And B-30 on Diesel Engine Performances and Emissions Perbandingan Biodiesel B-20 Dan B-30 pada Kinerja Mesin Diesel Dan Emisinya. Scientific Contributions Oil and Gas, 39, 7–8. http://www.journal.lemigas.esdm.go.id.

Amine, M., Awad, E. N., Ibrahim, V. & Barakat, Y., 2018, Effect of ethyl acetate addition on phase stability, octane number and volatility criteria of ethanol-gasoline blends. Egyptian Journal of Petroleum, 27(4), 567–572. https://doi.org/10.1016/j.ejpe.2017.08.007.

Andersen, V.F., Anderson, J.E., Wallington, T.J., Mueller, S.A., & Nielsen, O.J., 2010, Vapor pressures of alcohol-gasoline blends. Energy and Fuels, 24(6), 3647–3654. https://doi.org/10.1021/ef100254w.

Auzani, A.S., Clements, A.G., Hughes, K. J., Ingham, D.B. & Pourkashanian, M, 2021, Assessment of Ethanol Autoxidation as a Drop-in Kerosene and Surrogates Blend with a New Modelling Approach. Heliyon, 7(6), 1–11. https://doi.org/10.1016/j.heliyon.2021.e07295.

Chuck, C.J., & Donnelly, J, 2014a, The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene. Applied Energy, 118, 83–91. https://doi.org/10.1016/j.apenergy.2013.12.019.

Chuck, C.J. & Donnelly, J, 2014b, The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene. Applied Energy, 118, 83–91. https://doi.org/10.1016/j.apenergy.2013.12.019.

Fajar, R., Setyo Wibowo, C. & Yubaidah, S., 2011, Oxidation Stability Improvement for Jatropha Lemigas Scientific Contributions Rizqon Fajar, Et Al. Oxidation Stability Improvement for Jatropha Biodiesel to Meet The International Standard For Automotive Applications.

Hassan, S.H., Attia, N.K., Diwani, G.I. El, Amin, S.K., Ettouney, R.S. & El-Rifai, M.A., 123 C.E., Catalytic hydrocracking of jatropha oil over natural clay for bio-jet fuel production. https://doi.org/10.1038/s41598-023-40500-2.

Jia, T., Zhang, X., Liu, Y., Gong, S., Deng, C., Pan, L. & Zou, J.J., 2021, A comprehensive review of the thermal oxidation stability of jet fuels. In Chemical Engineering Science (Vol. 229). Elsevier Ltd. https://doi.org/10.1016/j.ces.2020.116157.

Lapuerta, M., Rodríguez-Fernández, J., Patiño-Camino, R., Cova-Bonillo, A., Monedero, E. & Meziani, Y. M., 2020, Determination of optical and dielectric properties of blends of alcohol with diesel and biodiesel fuels from terahertz spectroscopy. Fuel, 274. https://doi.org/10.1016/j.fuel.2020.117877.

Lown, A.L., Peereboom, L., Mueller, S. A., Anderson, J. E., Miller, D.J., & Lira, C.T., 2014, Cold flow properties for blends of biofuels with diesel and jet fuels. Fuel, 117(PART A), 544–551. https://doi.org/10.1016/j.fuel.2013.09.067.

Shirazi, S.A., Abdollahipoor, B., Windom, B., Reardon, K.F. & Foust, T.D., 2020, Effects of blending C3-C4 alcohols on motor gasoline properties and performance of spark ignition engines: A review. Fuel Processing Technology, 197(August 2019), 106194. https://doi.org/10.1016/j.fuproc.2019.106194.

Tran, S., Brown, A. & Olfert, J.S., 2020, Comparison of Particle Number Emissions from In-Flight Aircraft Fueled with Jet A1, JP-5 and an Alcohol-to-Jet Fuel Blend. https://doi.org/10.1021/acs.energyfuels.0c00260.

Turner, J.W.G., Pearson, R.J., Dekker, E., Iosefa, B., Johansson, K. & ac Bergström, K., 2013, Extending the role of alcohols as transport fuels using iso-stoichiometric ternary blends of gasoline, ethanol and methanol. Applied Energy, 102, 72–86. https://doi.org/10.1016/j.apenergy.2012.07.044.

Xie, S., Li, Z., Luo, S. & Zhang, W., 2024, Bioethanol to jet fuel: Current status, challenges, and perspectives. In Renewable and Sustainable Energy Reviews (Vol. 192). Elsevier Ltd. https://doi.org/10.1016/j.rser.2023.114240.

Yang, J., Xin, Z., He, Q. (Sophia), Corscadden, K. & Niu, H., 2019, An overview on performance characteristics of bio-jet fuels. In Fuel (Vol. 237, pp. 916–936). Elsevier Ltd. https://doi.org/10.1016/j.fuel.2018.10.079.