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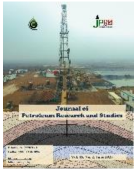

Improvements and Limits in the Search for Lead-Free Aviation Fuel in Iraq: A Mini Review

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Abstract

The continued emission of leaded aviation fuel has raised serious public health concerns among aviation companies. This study emphasizes the pressing need to identify alternative fuel options, highlighting how Aviation gasoline AVGAS has historically influenced engine performance and emission levels. As a high-octane gasoline critical to piston-engine aircraft, AVGAS has been linked to significant human health risks due to its lead content. Regulatory bodies such as the Environmental Protection Agency (EPA) and the Federal Aviation Administration (FAA) have advocated for transitioning from analog to digital systems to address these concerns. This shift requires thorough investigation and adherence to safety standards. Recent advancements, such as the use of high-octane mogas with a RON-98 rating, demonstrate promising outcomes in maintaining aircraft performance while mitigating environmental harm. Nevertheless, challenges remain, including engine compatibility, vapor lock risks, and regulatory compliance, underscoring the necessity for continued collaboration between fuel developers and aircraft manufacturers. This review explores the environmental impact of AVGAS, its effects on emissions and engine function, and sets the groundwork for future sustainable aviation practices.

Keywords: Fuel, avgas, gasoline, octane number, lead, emissions.

التحسينات والقيود في البحث عن وقود طيران خالٍ من الرصاص: مراجعة مختصرة

الخلاصة:

تولي شركات الطيران اهتمامًا كبيرًا بتقليل تأثيرات انبعاثات الوقود الطائر المحتوي على الرصاص على صحة العامة. لم يعد من الممكن تجاهل حقيقة أن هذا التحليل حول كيفية تأثير وقود الطائرات (AVGAS) على أداء المحركات ومستويات الانبعاثات يبرز الحاجة الملحة لاكتشاف خيارات وقود بديلة. لقد ثبت أن انبعاثات الرصاص منAVGAS، وهو وقود بنزين ذو تركيز عالٍ من الأوكتان وكان مهمًا في

تطوير محركات الطائرات، تشكل خطرًا كبيرًا على صحة الإنسان. وقد أوصت وكالة حماية البيئة (EPA) وإدارة الطيران الفيدرالية (FAA)، إلى جانب منظمات تنظيمية أخرى، بضرورة التحول من الأنظمة التناظرية إلى الأنظمة الرقمية في هذا الصدد. وهذا يتطلب طرق تحقيق أكثر شمولًا، وبعد ذلك سيكون مسموحًا به بشرط أن يفي بجميع معايير السلامة وفقًا لقوانينهم المنفصلة. تشير النتائج الحديثة، مثل دراسة وقود موغاس ذو الأوكتان العالي والذي يحمل تصنيفRON-98 ، إلى دعم الفكرة بأن الجهود كانت فعّالة في الحفاظ على قدرات الطائرات مع تقليل الأضرار البيئية في الوقت نفسه. ومع ذلك، لا تزال هناك تحديات، مثل التوافق مع المحركات، مشاكل قفل البخار، أو الموافقات التنظيمية التي تتطلب تعاونًا مستمرًا بين موردي الوقود وصانعي الطائرات.

1. Introduction

Gasoline, primarily derived from crude petroleum, is a volatile mixture of flammable liquid hydrocarbons used predominantly as fuel for internal combustion engines. It contains impurities such as hydrocarbons, nitrogen, oxygen, sulfur, and trace metals. The octane number of gasoline increases linearly with the proportion of antiknock agents, improving engine performance and reducing emissions when fuel additives are incorporated.

Lead compounds, known as lead alkyls particularly tetraethyl lead (TEL) and tetramethyl lead (TML)—have historically been added to fuel to prevent engine knocking, which reduces efficiency and fuel economy. These additives enhance gasoline's resistance to knocking, making it more suitable for automotive engines. However, they also damage catalyst materials in emission-control devices. Consequently, many countries have mandated the use of unleaded or reduced-lead fuels.

Modern methods to enhance antiknock properties include the use of high-octane oxygen-containing substances known as oxygenates, with ethanol being among the most common. TEL, still used in Iraqi pool gasoline even in low doses, is considered one of the most hazardous additives. Since World War II, gasoline has become one of the world's most critical resources, particularly for personal vehicles. Early 20th-century automotive engineers recognized the benefits of knock-free engine operation in improving efficiency and smoothness.

Fuels with lower sensitivity to operational conditions are preferred, as sensitive fuels show greater differences in performance under varied intake mixture temperatures and engine speeds. Given that gasoline production can represent 60–70% of a refinery's total income, it remains a vital product. Factors such as crude oil origin, refining methods, and additives influence gasoline's properties and environmental impact. Aromatic hydrocarbons like benzene, toluene, and xylenes contribute to increased emissions of reactive organic compounds.

Engine knock significantly reduces combustion efficiency. It can be addressed by refining engine architecture, tuning performance, and using high-quality fuels. Refineries modify gasoline to achieve desired antiknock quality using both processing and additives. While TEL and TML were once common in increasing octane ratings and reducing knock, concerns over public health particularly among children have led to the development of alternatives to traditional leaded aviation gasoline (AVGAS).

AVGAS remains standard for piston-engine aircraft, prompting extensive research into cleaner substitutes such as mogas, alcohol-based additives, and fuel blends that reduce or eliminate lead while preserving engine performance. Recent studies suggest that high-octane mogas (RON-98) may serve as a viable replacement, with ongoing research needed to assess its impact on performance and pollution. Sustainable fuel development must comply with aviation regulations while aiming for environmental and health safety.

Aviation fuel technology has evolved rapidly since the Wright brothers' 1903 flight, accelerating during World War II. The invention of the gas turbine engine (or "turbojet") led to the development of aircraft turbine fuel (avtur). Commercial airliners use jet or gas turbine engines for long-distance transport, while piston-engine aircraft powered by AVGAS are common in agriculture, flight training, and general aviation.

Despite its benefits in engine performance, AVGAS poses environmental and health hazards due to its TEL content. High-octane ratings improve resistance to knocking but come with serious health concerns. Elevated blood lead levels can lead to cancer in adults and intellectual impairments in children. The continued use of leaded aviation gasoline in piston-engine aircraft remains a critical challenge for the industry, underscoring the need for cleaner alternatives.

Regulatory bodies such as the FAA and EPA have recommended transitioning to unleaded fuels, stressing the importance of reducing aviation-related pollution and safeguarding public health while maintaining flight safety.

2. Characteristics and Importance of Aviation Gasoline (AVGAS)

Aviation gasoline, or AVGAS, is a specialized high-octane fuel formulated by refining and blending conventional gasoline. Designed specifically for small piston-engine aircraft used in general aviation, AVGAS allows the air-fuel mixture to be compressed further without igniting prematurely due to its elevated octane rating.

These aircraft, typically utilized in agricultural applications, flight training, and by private pilots or flying clubs, operate piston engines that resemble automotive spark ignition engines but require more robust fuel to meet demanding operational conditions. A key distinction between AVGAS and motor gasoline lies in its higher octane value, which quantifies the fuel's resistance to pre-ignition, commonly known as knocking. A higher octane rating permits greater compression of the fuel-air mixture before spontaneous combustion, improving engine efficiency and reliability.

AVGAS also differs in its chemical composition from automotive gasoline. It contains fewer volatile components, offering enhanced stability and making it more suitable for the high-performance and variable-altitude conditions experienced during flight. This stability is essential for ensuring reliable engine performance and safety in general aviation.

The phenomenon of knocking, or premature combustion of the air-fuel mixture in spark ignition (SI) engines, plays a critical role in determining engine performance. If left unchecked, knocking can lead to mechanical stress, shorten engine component lifespan, and degrade fuel efficiency. Repeated knocking results in inefficient combustion, reduced fuel economy, and lower power output, as the engine fails to fully harness the fuel's energy potential.

General specifications for aviation fuel (Avgas), as proposed by various researchers, arranged without a particular order of priority:

1. High heat content to maximize payload or range. This could indicate a high energy density or high specific energy.
2. Effective atomization.
3. Quick evaporate.
4. Good burning qualities, such as the capacity to relight at an altitude.
5. minimal chance of an explosion.
6. High capacity for specific heat.
7. Devoid of impurities.
8. Lowest possible carbon production.
9. Good storage and pumping qualities, low freezing point to enable operation at altitude, and low viscosity and strong lubricity.
10. Strong chemical and thermal stability.
11. Affordability and broad availability.
12. Combustion products that are acceptable for the environment.
13. Good handling and ground storage qualities.

3. Environmental Impact of Aviation Emissions

In 2005, the Federal Aviation Administration (FAA) conducted a comprehensive analysis of aviation emissions, detailing the primary constituents and their environmental implications. According to the report, gas-powered aircraft engines emit predominantly carbon dioxide (approximately 70%) and water vapor (around 29%), with smaller portions of nitrogen oxides

(NO_x), hydrocarbons (HC), and carbon monoxide (CO). Notably, piston-engine aircraft are also a source of lead emissions.

The FAA report emphasizes the significant environmental impact of aircraft exhaust, distinguishing between emissions produced during ground operations and those released at higher altitudes. This differentiation is crucial in understanding the dual nature of aviation pollution. Near the Earth's surface, emissions are categorized as local air pollutants, whereas at cruising altitudes, they contribute to the accumulation of greenhouse gases in the upper atmosphere. Water vapor emissions at high altitudes are particularly concerning, as they can intensify the greenhouse effect. Ground operations, including taxiing, takeoff, and landing, account for approximately 10% of total hydrocarbon and carbon monoxide emissions. In contrast, the remaining 90% of these emissions occur at higher altitudes during cruising flight. The steady growth in global air travel over recent years has significantly amplified these emission levels, prompting renewed discussions about the sustainability of continued expansion in the aviation sector.

For piston-engine aircraft using aviation gasoline (AVGAS), the combustion process releases lead oxide, a hazardous byproduct. In the absence of ethylene dibromide (EDB), a necessary lead scavenger, lead oxide can accumulate on vital engine components such as spark plugs and valves, potentially leading to long-term engine degradation. Furthermore, during fuel distribution, refueling, and engine operation, volatile alkyl lead compounds—particularly tetraethyl lead—are emitted into the atmosphere, posing serious environmental and health risks.

Since 1964, the Experimental Aircraft Association (EAA) has explored using mogas (motor gasoline) as an alternative to leaded aviation gasoline (AVGAS). However, FAA certification via Supplemental Type Certificates (STCs) is necessary before mogas can be legally used in aircraft. In 2010, Cessna noted FAA-approved ethanol-based fuels were available for a few single-engine planes.

Aircraft engines designed solely for gasoline often struggle with compatibility when using alternative fuels, especially due to outdated materials. Components like seals and pumps may need modern replacements, but design constraints complicate these adaptations. Notably, mogas's high vapor pressure makes it prone to vapor lock, a common issue in aviation fuel systems, worsened when ethanol is blended.

Fuel system components—from tanks and hoses to combustion chambers—are typically optimized for AVGAS. Many of these materials are incompatible with ethanol-blended fuels. Despite these challenges, the harmful environmental effects of leaded AVGAS remain a concern, with aviation being the largest lead emissions source. This has led to research into eco-friendlier alternatives.

Roughly 2,000 new piston-engine aircraft are built annually, and over 235,000 still use leaded AVGAS. Though general aviation is expected to grow slightly by 2025, the environmental footprint of piston-engine aircraft—often overlooked—remains significant.

Masiol and Harrison (2014) emphasized the environmental impact of piston engines, noting the lack of accurate fuel consumption and emissions data. These engines are commonly used in smaller, recreational aircraft, yet research has primarily focused on gas turbines. This gap complicates assessments of piston engine pollution, especially with rising global air traffic.

Zaporozhets and Synylo (2015) explored aviation emissions' contributions to greenhouse gases. While piston engines operate at lower altitudes, they still produce emissions like NOx (nitrogen oxide for any number of oxygen) and CO_2, contributing to environmental harm. Aviation accounts for about 2.7% of global greenhouse gases—substantially less than land transport but still impactful.

Efforts to reduce aviation pollution include using alternative fuels and upgrading ground equipment. However, reducing emissions from piston engines remains difficult due to trade-offs between noise, performance, and pollutant output.

Yacovitch et al. (2016) addressed data gaps by testing emissions from 10 common piston engines. They found emissions varied based on factors like pilot behavior, engine design, and fuel additives. Piston engines emit lower NOx but higher hydrocarbons and CO compared to gas turbines. Their research emphasized the need for deeper analysis to understand and control piston engine emissions.

4. Health and Environmental Impact

Piston engine emissions pose serious health and environmental risks, as the ultra-fine particles they emit—ranging from 0.049 to 0.108 microns—can enter the respiratory systems of both humans and animals. These pollutants contribute to air pollution and can cause a variety of health issues.

Environmental factors such as wind, humidity, and the proximity of airport operations to populated areas influence how and where these emissions settle. Even as lead concentrations have declined, past use of leaded AVGAS at airports still concerns nearby communities.

Leaded AVGAS contains ethylene dibromide (EDB), used as a scavenger to prevent lead oxide deposits in engine parts like spark plugs and valves. However, EDB itself poses significant health and environmental risks. The **EPA classifies EDB as a probable

Emissions from piston-engine aircraft contribute significantly to air pollution, with adverse effects on both environmental and human health. The particulate matter released, typically ranging in size from 0.049 to 0.108 microns, is small enough to penetrate the respiratory systems of humans and animals. Factors such as wind direction, humidity, and the proximity of engine operations (e.g., startups, pre-flight checks, and takeoffs) to residential areas influence the local dispersion and deposition of these emissions. Despite a reduction in ambient lead levels over time, historical use of leaded AVGAS at many airports continues to pose environmental concerns for surrounding communities.

Leaded AVGAS contains ethylene dibromide (EDB), a compound used to prevent the buildup of lead oxide on engine components such as spark plugs and valves. However, EDB is associated with significant health risks. The U.S. Environmental Protection Agency (EPA) classifies EDB as a probable human carcinogen, citing evidence of non-cancer health effects in both humans and animals through inhalation and ingestion. As a result, the EPA has established reference exposure limits to guide safe environmental and occupational practices. Continued monitoring and the implementation of mitigation strategies are essential to reducing the impact of piston engine emissions on health and the environment.

4.1. Legacy Design and Chemical Dependency of Piston Aircraft

The current fleet of piston-engine aircraft was built around the chemical and physical properties of aviation gasoline (AVGAS), which has remained largely unchanged for 70 years. This consistency has ensured high operational safety. To prevent engine knocking, tetraethyl lead (TEL) is added to AVGAS to raise its octane level. However, TEL is a known toxic compound. Studies have linked lead exposure to serious health effects—particularly in children, where it impairs brain development and lowers IQ, and in adults, where it can cause cardiovascular issues and kidney damage [22].

4.2. Regulatory and Environmental Concerns

In 2006, Friends of the Earth (FOE) petitioned the U.S. Environmental Protection Agency (EPA) to determine whether lead emissions from general aviation (GA) aircraft harm public health or to at least investigate and publish findings [22]. The ongoing reliance on leaded AVGAS in piston-engine aircraft has become a major concern, especially in the United States, where over 167,000 of these aircraft are still in operation. This aging fleet is slow to transition, making it highly dependent on the continued availability of suitable leaded fuel [22].

4.3. Industry Response and the Shift Toward Unleaded Alternatives

While TEL effectively prevents engine knock, it poses severe risks when inhaled, ingested, or absorbed through the skin [22]. These risks have driven collaboration between aviation industry stakeholders and regulatory bodies such as the FAA and EPA to develop and implement an unleaded alternative that maintains safety and performance standards while reducing environmental and health impacts. This transition is critical for long-term sustainability, especially in light of a sluggish aircraft market and financial constraints within the industry [22].

4.4. Ethylene Dibromide (EDB) as a TEL Scavenger

To counteract TEL buildup, ethylene dibromide (EDB) is added to leaded AVGAS, typically in a 1:2 lead-to-bromine atom ratio. Although data on EDB emissions from piston aircraft are limited, it is recognized that these planes contribute EDB to the atmosphere. Even at concentrations below 1.06 mg/L, as seen in similar fuels used by light-duty vehicles, EDB poses environmental and health risks [22].

4.5. Environmental Pathways and Persistence of EDB

Beyond atmospheric concerns, EDB can contaminate groundwater through leaking storage tanks and fuel spills. Once in aquifers, EDB is highly persistent and difficult to remove, threatening long-term water quality. Due to its toxicity and persistence, the EPA supports reducing the use of EDB-containing AVGAS and continues to monitor its levels in the environment [22].

4.6. Human Exposure to TEL and Alkyl Lead Compounds

Evaporative emissions from fuel storage, aircraft refueling, pre-flight inspections, fuel dumping, and venting are primary exposure routes to TEL. Pilots often drain small amounts of fuel during routine checks, which can lead to environmental contamination [10]. Alkyl lead compounds, once released into the atmosphere, are broken down through oxidation, photolysis, and reactions with hydroxyl radicals—but may persist for hours to days depending on environmental conditions [10].

4.7. Occupational Hazards and Health Risks

Personnel such as pilots, mechanics, and fuel handlers are at elevated risk due to frequent inhalation and potential skin contact with TEL and alkyl lead. Inhaled alkyl lead enters the bloodstream more rapidly than particulate lead, heightening its toxicity. The EPA's Persistent, Bioaccumulative, and Toxic (PBT) National Action Plan has identified these groups as particularly vulnerable [10]. Tasks like fuel handling, engine servicing, and spill management significantly raise the likelihood of dermal and inhalation exposure, necessitating strict safety protocols and ongoing health monitoring [10].

5. Conclusions

Aviation gasoline (AVGAS) has long been the standard fuel for piston-engine aircraft, yet its continued reliance on tetraethyl lead (TEL) presents serious public health and environmental challenges. Lead exposure has been linked to intellectual impairment in children and cardiovascular and kidney damage in adults, while ethylene dibromide (EDB), added as a lead scavenger, is classified by the EPA as a probable human carcinogen. With hundreds of thousands of piston-engine aircraft still operating on leaded AVGAS, and aviation remaining the largest source of lead emissions, the urgency for transition is undeniable.

Regulatory bodies including the FAA and EPA have actively pushed for unleaded alternatives, and recent research indicates that high-octane mogas (RON-98) shows promising potential as a substitute. However, challenges such as vapor lock, engine material incompatibility, and the need for FAA certification through Supplemental Type Certificates (STCs) must be addressed before widespread adoption. Collaboration between fuel developers, aircraft manufacturers, and regulatory authorities remains essential to ensuring that any replacement fuel meets both safety and performance standards.

In conclusion, while no single solution has yet fully replaced leaded AVGAS, continued research and industry cooperation offer a clear path toward cleaner, lead-free aviation that protects both public health and the environment.

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