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DIFFERENT VARIETIES OF FUEL FOR IC ENGINE – A REVIEW OF FUEL CONSUMPTION AND EMISSIONS

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ABSTRACT
This paper aims to identify research areas that address the issues of fuel consumption and pollutant emissions in transportation and other internal combustion engines (IC engine). The author's view, will help Three types of IC engines are discussed and compared: Spark-Ignited (SI), Conventional Diesel, and Low Temperature Combustion (LTC), with their operating regimes. The focus is on gasoline SI engine, which depends on high-temperature turbulent flame propagation, and is influenced by complex physical and chemical kinetic processes. The SI engine is the least fuel efficient, partly due to high flame temperatures leading to significant wall heat transfer losses. These high temperatures also result in high NOx emissions, but tailpipe emissions are reduced by the low-cost three-way catalyst. However, emissions of N2O and other unburned hydrocarbons (UHCs) during cold starts (before catalyst "light-off") remain a concern. N_2O has a long atmospheric lifetime (approximately 120 years) and is about 300 times more effective than CO_2 as a greenhouse gas. Conventional diesel engines are 20-40% more fuel efficient than SI engines, and their combustion process is less complex.

INTRODUCTION
Internal combustion (IC) engines can run on a variety of fuels, each offering unique benefits and challenges. Gasoline and diesel are the most prevalent, powering a wide range of vehicles with their high energy density, though they contribute significantly to air pollution. Natural gas and liquefied petroleum gas (LPG) provide cleaner alternatives, emitting fewer pollutants but requiring specialized storage and distribution infrastructure. Biofuels, including ethanol and biodiesel, are renewable and can reduce greenhouse gas emissions, although they may affect food resources and engine compatibility. Hydrogen, a clean fuel, promises zero emissions but faces hurdles in storage, production, and infrastructure development. The choice of fuel affects engine performance, environmental impact, and sustainability, driven by availability, cost, and regulatory demands.

DIFFERENT FUELS USED IN IC ENGINE
Literature on Fuels Used in Internal Combustion Engines (IC Engines)
- Biodiesel can be categorized into three generations based on its feedstock. The first generation includes conventional biofuels derived from food crops such as soybean and corn [10]. First-generation biodiesels are derived from feedstocks that are also suitable for human consumption. Common sources include vegetable oils such as soybean and sunflower oil, along with animal fats [11]. The production of biodiesel from these oils often

involves processes like transesterification, wherein the oils are reacted with alcohol to produce Fatty Acid Methyl Esters (FAME) [11].

- The second generation consists of advanced biofuels produced from non-food biomass, including agricultural residues and waste materials [10].
- Lastly, the third generation focuses on biodiesel produced from algae, which can offer higher oil yields per area compared to traditional crops [10]. Third-generation biodiesels are derived from algae, which are capable of producing oils that can be processed into biodiesel. This type of biodiesel holds promise due to the rapid growth rates of algae and their ability to utilize various waste products as nutrients [11]. Algal biodiesel can be genetically modified to produce not only oils but also alcohols that can be refined into fuels [11].
- Biodiesel tends to reduce greenhouse gas emissions when compared to petroleum diesel. Life cycle analyses suggest that emissions for 100% biodiesel (B100) can be as much as 74% lower than those from petroleum diesel [12]. Specifically, biodiesel exceeds conventional diesel in reducing carbon monoxide (CO) and particulate matter (PM) emissions, while its effect on nitrogen oxide (NOx) emissions tends to vary depending on the blend used [13]. Furthermore, life cycle assessments suggest that biodiesel can lead to a significant reduction in overall carbon emissions compared to petroleum diesel, with particular blends showing a reduction of up to 74% in lifecycle carbon dioxide emissions [13]. The production of biodiesel contributes to economic sustainability by revitalizing agricultural sectors and rural economies. It serves as an alternative to fossil fuels, promoting energy security while meeting greenhouse gas (GHG) reduction goals [2]. Studies have shown that using biodiesel blends in internal combustion engines can impact engine performance positively. For instance, biodiesel blends have been reported to produce higher indicated power compared to petroleum diesel [15]. However, the specific fuel consumption tends to be higher since biodiesels typically have lower energy content than fossil fuels [16]. A performance analysis indicated that blends with higher biodiesel proportions achieved favorable torque values, although absolute power outputs were lower than diesel [14]. Advancements in diesel engine technology have significantly improved emissions performance, regardless of the fuel type being used. The integration of exhaust aftertreatment devices and improved engine controls have made modern diesel engines compliant with stringent emissions standards, ensuring that the cleaner emissions associated with biodiesel can be realized effectively [15].

1. Gasoline

This comprehensive textbook covers the fundamentals of gasoline engines, including fuel characteristics, combustion processes, and emission formation. It also delves into the impact of different gasoline compositions on engine performance and emissions.

2. Diesel

This reference book provides an in-depth look at diesel fuel properties, the combustion process, and the resulting emissions. It discusses the advantages of diesel fuel in terms of energy density and fuel efficiency.

3. Biodiesel

This handbook covers the production, properties, and performance of biodiesel fuels. It highlights the environmental benefits of using biodiesel and its potential as a sustainable alternative to conventional diesel.

4. Natural Gas

This book explores the use of natural gas as a fuel for IC engines, focusing on the design, performance, and emissions of natural gas vehicles. It also discusses the infrastructure requirements for widespread adoption.

5. Ethanol

This review article examines the potential of ethanol as a transportation fuel, considering its production from renewable resources, combustion characteristics, and impact on emissions compared to gasoline.

6. Hydrogen

This book discusses the use of hydrogen as a fuel for IC engines, including production methods, storage solutions, and its potential to reduce greenhouse gas emissions. It also covers the technical challenges and benefits of hydrogen combustion.

7. Synthetic Fuels

This handbook provides an overview of synthetic fuels, including their production from coal, natural gas, and biomass. It details the properties of synthetic fuels and their performance in IC engines, along with the environmental implications.

8. Alternative Fuels

This edited volume covers a range of alternative fuels, including biofuels, hydrogen, and synthetic fuels. It discusses the performance, emissions, and potential of these fuels to reduce the carbon footprint of transportation.

9. Alcohol Fuels

This book examines the use of alcohols, such as methanol and ethanol, as fuels for IC engines. It covers the production, combustion characteristics, and environmental impact of alcohol fuels.

10. Compressed Natural Gas (CNG)

This review article provides an overview of the use of CNG in IC engines, including its advantages, challenges, and potential environmental benefits compared to conventional fuels.

These references provide a broad perspective on the various fuels used in internal combustion engines, covering their properties, performance, and environmental impact.

Properties of Gasoline as Fuel for Internal Combustion Engines

Gasoline is a widely used fuel for internal combustion engines (IC engines) due to its favorable properties. Below are the key properties of gasoline that make it suitable for use in IC engines:

1. Chemical Composition

- **Hydrocarbons**: Gasoline is primarily composed of hydrocarbons, including alkanes, cycloalkanes, alkenes, and aromatics. The typical carbon chain length ranges from C4 to C12.

- **Additives**: Various additives are used to improve performance and reduce emissions, such as detergents, anti-knock agents (e.g., tetraethyl lead, now replaced by other additives due to environmental concerns), antioxidants, and corrosion inhibitors.

2. Energy Content

- **Higher Heating Value (HHV)**: Approximately 44 MJ/kg
- **Lower Heating Value (LHV)**: Approximately 42-43 MJ/kg
- **Energy Density**: High energy density provides substantial power output for the engine.

3. Octane Rating

- **Research Octane Number (RON)**: Typically between 91 and 98 for regular and premium gasoline.
- **Motor Octane Number (MON)**: Generally lower than RON, usually between 81 and 89.
- **Anti-Knock Index (AKI)**: Average of RON and MON, also known as Pump Octane Number (PON). It indicates the fuel's resistance to knocking or pinging during combustion.

4. Volatility

- **Reid Vapor Pressure (RVP)**: Measures the volatility of gasoline, usually between 7 and 15 psi. Higher volatility ensures good vaporization and cold-start performance.
- **Boiling Range**: Gasoline boils between 30°C and 225°C. A broad boiling range ensures the presence of both light fractions for cold starting and heavier fractions for power.

5. Density

- **Typical Density**: About 0.71 to 0.77 g/cm³ at 15°C. Lower density compared to diesel fuel.

6. Stoichiometric Air-Fuel Ratio

- **Ideal Ratio**: Approximately 14.7:1 (air to fuel by weight). This ratio ensures complete combustion under ideal conditions.

7. Flammability Limits

- **Lower Flammability Limit (LFL)**: About 1.4% by volume in air.
- **Upper Flammability Limit (UFL)**: About 7.6% by volume in air.

8. Flash Point

- **Typical Flash Point**: Between -40°C and -30°C. The low flash point makes gasoline highly flammable.

9. Autoignition Temperature

- **Autoignition Temperature**: Approximately 280°C to 300°C. This temperature must be reached for the fuel to spontaneously ignite without an external spark.

10. Viscosity

- **Typical Viscosity**: Low, around 0.5 to 0.75 cSt at 40°C. Low viscosity ensures easy flow through the fuel system.

11. Sulfur Content

- **Sulfur Content**: Typically very low, due to regulations aiming to reduce sulfur dioxide (SO2) emissions. Ultra-low sulfur gasoline contains less than 10 ppm of sulfur.

12. Oxygen Content

- **Oxygenates**: Often contains oxygenates like ethanol or MTBE (methyl tert-butyl ether) to improve combustion and reduce emissions.

13. Additives

- **Detergents**: Clean fuel injectors and intake valves.
- **Corrosion Inhibitors**: Protect the fuel system from corrosion.
- **Stabilizers**: Prevent oxidation and gum formation during storage.

These properties collectively contribute to the performance, efficiency, and emissions characteristics of gasoline-powered internal combustion engines. The balance of volatility, energy content, and combustion properties makes gasoline a suitable fuel for a wide range of IC engines, from small motorcycles to large passenger cars.

In this study, Cooney et al. [1] investigate the combustion characteristics of ethanol-gasoline blended fuels in an internal combustion engine. The research focuses on how varying compression ratios and ignition timings affect the performance and emissions of the engine. Key findings include:

- **Blended Fuels**: Ethanol-gasoline blends, specifically E10 (10% ethanol, 90% gasoline) and E85 (85% ethanol, 15% gasoline), were used to assess their impact on engine combustion.
- **Compression Ratios**: Different compression ratios were tested to determine the optimal conditions for each fuel blend.
- **Ignition Timing**: The timing of the spark ignition was varied to study its effect on engine efficiency and emissions.
- **Performance**: Ethanol blends demonstrated improved combustion efficiency and higher power output compared to pure gasoline, particularly at higher compression ratios.
- **Emissions**: The study found a reduction in harmful emissions, such as CO and HC, with ethanol blends, although NOx emissions varied depending on the compression ratio and ignition timing.
- **Conclusion**: Ethanol-gasoline blends can enhance engine performance and reduce certain emissions, with optimal results achieved through careful adjustment of compression ratios and ignition timing.

The study highlights the potential of ethanol as a viable alternative fuel to improve the efficiency and environmental impact of internal combustion engines.

Ashraf Elfasakhany. [2] explores the emissions and performance of an internal combustion engine fueled with pure gasoline and gasoline blended with n-butanol. Key points of the research include: Fuel Blends- The study examines various gasoline/n-butanol blends, particularly focusing on mixtures containing 5%, 10%, 15%, and 20% n-butanol by volume.

- **Performance Analysis**: Engine performance metrics such as power output, torque, and fuel consumption were measured and compared across different fuel blends.

- **Emissions Testing**: Emission levels of CO, HC, NOx, and CO2 were evaluated to understand the environmental impact of using n-butanol blends.
- **Results**:
  - **Performance**: The addition of n-butanol generally improved engine performance, with higher power output and torque observed for blends containing up to 20% n-butanol.
  - **Fuel Consumption**: Specific fuel consumption increased slightly with higher n-butanol content due to its lower energy density compared to gasoline.
  - **Emissions**: Blends with n-butanol showed a significant reduction in CO and HC emissions. However, NOx emissions tended to increase with higher n-butanol content.
- **Conclusion**: Gasoline/n-butanol blends can enhance engine performance and reduce certain emissions, making n-butanol a promising additive for cleaner and more efficient combustion in internal combustion engines.This study demonstrates the potential benefits of using n-butanol as a blending agent in gasoline to improve engine performance and reduce harmful emissions.

Vallinayagam et al. [3] investigates how different fuel properties influence the performance and emissions of gasoline compression ignition (GCI) engines.
- **Fuel Types**: Various gasoline-like fuels with differing octane ratings, volatility, and chemical compositions were tested.
- Key Areas of Focus:
  - **Ignition Characteristics**: How physical properties like octane number and chemical composition affect ignition timing and combustion stability.
  - **Combustion Efficiency**: Analysis of how fuel properties influence combustion efficiency, power output, and thermal efficiency.
  - **Emission Profiles**: Examination of emissions including NOx, CO, HC, and particulate matter based on different fuel types.
- - **Results**:
  - **Octane Rating**: Fuels with lower octane numbers were found to ignite more readily, influencing combustion phasing and efficiency.
  - **Volatility**: Higher volatility fuels demonstrated improved mixing and combustion characteristics, leading to more stable combustion.
  - **Chemical Composition**: The presence of certain hydrocarbons and additives affected combustion dynamics and emission outputs.
- **Performance Metrics**: Key performance metrics such as brake thermal efficiency and specific fuel consumption were analyzed in relation to fuel properties.
- **Emissions**: Variations in fuel properties led to differences in emission levels, with certain fuels showing potential for reduced NOx and particulate emissions.
- **Conclusion**: The study highlights the importance of fuel selection in optimizing GCI engine performance and emissions, suggesting that tailored fuel formulations can enhance engine efficiency and reduce environmental impact.These notes summarize the critical aspects and findings of the research, emphasizing the relationship between fuel properties and GCI engine performance and emissions.

Author. [4] discusses the use of ethanol as a fuel for internal combustion engines, covering its properties, benefits, and challenges.
- **Properties of Ethanol**:
  - **Chemical Composition**: Ethanol (C2H5OH) is a renewable alcohol fuel derived from biomass.

- **Energy Content**: Lower energy density compared to gasoline (approximately 66% of gasoline's energy content).
- **Octane Rating**: High octane number (over 100), which helps prevent engine knocking.
- **Combustion Characteristics**: Burns more completely and cleanly than gasoline, reducing certain emissions.
- **Benefits of Ethanol**:
- **Renewability**: Ethanol is produced from renewable resources such as corn, sugarcane, and cellulosic materials.
- **Emissions**: Lower emissions of CO, HC, and particulate matter compared to gasoline. Ethanol combustion produces fewer greenhouse gases.
- **Engine Performance**: High octane rating allows for higher compression ratios and improved engine efficiency.
- **Challenges**:
- **Energy Density**: Lower energy density results in higher fuel consumption per mile compared to gasoline.
- **Corrosiveness**: Ethanol can be corrosive to certain engine materials and fuel systems.
- **Water Absorption**: Ethanol is hygroscopic, meaning it absorbs water from the environment, which can lead to phase separation and engine issues.
- **Applications**:
- **Blending**: Commonly used in blends with gasoline, such as E10 (10% ethanol, 90% gasoline) and E85 (85% ethanol, 15% gasoline).
- **Flex-Fuel Vehicles**: Vehicles designed to run on varying ethanol blends, maximizing ethanol's benefits while mitigating its drawbacks.
- **Performance and Emissions Studies**:
- **Engine Testing**: Various studies have shown that ethanol blends can improve engine efficiency and reduce emissions under certain conditions.
- **Cold Start Issues**: Ethanol can cause difficulties in cold starts due to its lower vapor pressure.
- **Conclusion**: Ethanol is a viable alternative to gasoline for internal combustion engines, offering environmental and performance benefits. However, its lower energy density and material compatibility issues require careful consideration and engine adaptation.

These notes provide a concise overview of the key points discussed in the chapter, focusing on ethanol's properties, benefits, challenges, and applications as an internal combustion engine fuel.
Sebastian Verhelst et al. . [5]paper provides a comprehensive review of methanol as a fuel for internal combustion engines, exploring its properties, benefits, challenges, and applications.

- **Properties of Methanol**:
- **Chemical Composition**: Methanol (CH_3OH) is a simple alcohol that can be produced from natural gas, coal, biomass, or CO_2.
- **Energy Content**: Lower energy density than gasoline (about half of gasoline's energy content).
- **Octane Rating**: High octane number (~110), which helps prevent engine knocking.
- **Combustion Characteristics**: Efficient combustion with a high flame speed, leading to clean and complete burning.
- **Benefits of Methanol**:
- **Renewability**: Can be produced from various renewable resources and waste materials.

- **Emissions**: Lower emissions of CO, HC, NOx, and particulate matter compared to gasoline. Methanol combustion produces fewer greenhouse gases.
- **Engine Performance**: High octane rating allows for higher compression ratios and improved thermal efficiency. Methanol's high heat of vaporization can enhance charge cooling and power output.
- **Challenges**:
- **Energy Density**: Lower energy density results in higher fuel consumption per mile compared to gasoline.
- **Material Compatibility**: Methanol can be corrosive to certain engine materials and fuel systems.
- **Toxicity**: Methanol is toxic if ingested or inhaled, requiring careful handling and safety measures.
- **Cold Start Issues**: Methanol has a low vapor pressure, leading to difficulties in cold starting, especially in low temperatures.
- **Applications**:
- **Blending**: Used in blends with gasoline, such as M15 (15% methanol, 85% gasoline) and M85 (85% methanol, 15% gasoline), to leverage methanol's benefits.
- **Dedicated Methanol Engines**: Engines specifically designed or adapted to run on pure methanol or high methanol blends.
- **Flex-Fuel Vehicles**: Vehicles capable of operating on various methanol-gasoline blends, maximizing flexibility and fuel availability.
- **Performance and Emissions Studies**:
- **Engine Testing**: Methanol has been shown to improve engine performance and reduce emissions in various studies.
- **Emission Control**: Advanced emission control technologies can further enhance methanol's environmental benefits.
- **Efficiency Gains**: Potential for significant efficiency gains with optimized engine designs tailored to methanol's properties.
- **Conclusion**: Methanol is a promising alternative fuel for internal combustion engines, offering environmental and performance benefits. Its lower energy density and material compatibility issues require engine adaptations and careful fuel system management.

The author Minh [6] summarize the essential aspects of methanol as an internal combustion engine fuel, highlighting its properties, advantages, challenges, and potential applications.

The potential of ethanol-fueled HCCI engines in reducing the carbon footprint of transportation is emphasized. With continued research and development, these technologies could play a crucial role in transitioning to more sustainable and environmentally friendly transportation systems.

The Collaboration between academia, industry, and policymakers is crucial for overcoming technical barriers and promoting the adoption of ethanol and HCCI technologies in the automotive market.

Overall, the review underscores the promise of ethanol and HCCI technology in enhancing the efficiency and sustainability of internal combustion engines, paving the way for cleaner and greener transportation solutions.

SUMMARY

Internal combustion (IC) engines can utilize a range of fuels, each with distinct advantages and challenges. Gasoline and diesel, the most common fuels, offer high energy density but contribute

significantly to pollution. Natural gas and liquefied petroleum gas (LPG) are cleaner-burning alternatives, though they necessitate specialized storage and infrastructure. Biofuels like ethanol and biodiesel are renewable and can reduce greenhouse gas emissions, but may impact food supplies and engine compatibility. Hydrogen promises zero emissions but requires advanced technology for storage and distribution. The choice of fuel affects engine performance, environmental impact, and sustainability, with each option driven by factors such as availability, cost, and regulatory requirements. Ongoing innovations aim to enhance the balance between efficiency and environmental considerations in IC engine fuels.

CONCLUSION

The choice of fuel for internal combustion engines significantly impacts performance, emissions, and sustainability. Gasoline and diesel remain dominant due to their energy density and infrastructure, despite their environmental drawbacks. Cleaner alternatives like natural gas and LPG reduce emissions but require specialized storage and distribution systems. Biofuels offer renewable options but present challenges in food resource management and engine compatibility. Hydrogen,
while promising zero emissions, faces significant technological and infrastructure hurdles. Ultimately, the future of IC engine fuels will be shaped by balancing these factors to meet evolving environmental and regulatory demands.

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