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Low Emission Engines for Hybrid Electric Vehicles

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A B S T R A C T

This study delves into recent advancements in the development of low-emission engines specifically designed for Hybrid Electric Vehicles (HEVs). Emphasizing a core objective of minimizing environmental impact, the research assesses a range of strategies and technologies aimed at achieving reduced emissions in HEV powertrains. Significant approaches include the application of intelligent bi-fuel systems, Lyapunov-based control designs tailored for gasoline engines, and the incorporation of transient dynamic models featuring fuzzy-PID governors. Furthermore, the paper conducts a critical review of the current literature, providing a thorough overview of internal combustion engines and electric propulsion systems as integral elements of HEVs. The synthesis of these innovations highlights the crucial role played by low-emission engines in advancing the ecological sustainability of HEVs, positioning them as pivotal contributors to the evolution of environmentally conscious transportation. This exploration seeks to provide valuable insights for researchers, engineers, and policymakers engaged in the continual pursuit of cleaner and more efficient propulsion systems for hybrid electric vehicles.

Keywords: Low-emission engines, Hybrid Electric Vehicles (HEVs), Environmental impact mitigation, Emission reduction strategies,

1. Introduction

The quest for sustainable and environmentally-friendly transportation solutions has propelled extensive research into the realm of Hybrid Electric Vehicles (HEVs) globally. With a growing imperative to reduce the ecological impact of conventional vehicles, attention has shifted markedly toward the development of low-emission engines tailored explicitly for integration into HEV platforms. This paper delves into the innovative strategies and technologies aimed at curbing emissions within the context of hybrid electric propulsion systems.

HEVs stand as a pivotal bridge between traditional internal combustion engines and the burgeoning field of electric vehicles. Their unique powertrain configurations, amalgamating internal combustion engines with electric propulsion, present a promising avenue for achieving heightened fuel efficiency and a diminished environmental footprint. Central to this paradigm is the evolution and seamless integration of low-emission engines, which not only meet stringent emission standards but also optimize the overall performance of the vehicle.

Within this exploration, we navigate through the essential aspects of low-emission engine technologies for HEVs. From the implementation of intelligent bi-fuel systems to the utilization of advanced control designs and dynamic models, we scrutinize the varied approaches employed to attain minimal emissions. Furthermore, we conduct a critical examination of the existing literature encompassing internal combustion engines and electric propulsion systems, both integral components of HEVs, providing a comprehensive snapshot of the contemporary landscape.

In a rapidly evolving automotive landscape increasingly prioritizing sustainability, comprehending and advancing low-emission engine technologies for HEVs emerges as an imperative. This paper endeavors to enrich the ongoing discourse on eco-friendly propulsion systems, furnishing valuable insights for researchers, engineers, and policymakers vested in steering the course of sustainable transportation.

1.1 FUEL CELL TECHNOLOGY

1.1.1 **Hydrogen Fuel Cell**: A hydrogen fuel cell is an eco-friendly energy solution that transforms hydrogen and oxygen into electricity via an electrochemical process, generating water as its sole byproduct. It holds potential for diverse applications, such as transportation and power generation, owing to its emission-free characteristics. Despite challenges related to hydrogen production methods and costs, ongoing research strives to enhance fuel cell efficiency and affordability, paving the way for broader integration into the clean energy sector.

1.1.2 **Synthetic Fuel Cell:** A synthetic fuel cell is an electricity-generating technology that operates through electrochemical reactions, akin to conventional fuel cells. However, instead of relying on pure hydrogen, synthetic fuel cells utilize artificial fuels like synthetic methane or ammonia, frequently sourced from renewable resources. This approach presents potential benefits for energy storage, transportation, and integration with current infrastructure. Ongoing research aims to enhance efficiency and reduce costs, with the goal of establishing synthetic fuel cells as a practical and sustainable option for diverse applications in the energy industry.

1.1.3 **Alkaline Fuel Cell:** The alkaline fuel cell (AFC) is an electrochemical apparatus that produces electricity through the combination of hydrogen and oxygen in an alkaline electrolyte. In contrast to proton exchange membrane (PEM) fuel cells, AFCs employ a liquid alkaline solution as their electrolyte. Recognized for their efficiency, simplicity, and capacity to utilize non-precious metal catalysts, which helps reduce costs, AFCs find applications in space missions, stationary power generation, and specific vehicle niches. Continuous research seeks to improve their durability and broaden their commercial applicability across different sectors.

1.1.4 **Solid Polymer Fuel Cell:** A solid polymer fuel cell (SPFC), also referred to as a proton exchange membrane (PEM) fuel cell, is an electrochemical device that transforms hydrogen and oxygen into electricity using a solid polymer membrane. This membrane selectively allows the passage of protons while blocking electrons, facilitating the electrochemical reaction. Renowned for their high efficiency, rapid start-up, and versatility across applications such as transportation and stationary power generation, SPFCs are frequently employed in fuel cell vehicles due to their compact design and quick response times. Continuous research aims to enhance durability, decrease costs, and broaden their applications in various clean energy technologies.

Table 1 –Comparison between different types of fuel cells

Fuel cell type	**Operating temperature (Degrees Celsius)**	**Typical stack size**	**Efficiency**
Polymer electrolyte membrane	50-100	<1KW-100KW	60%
Alkaline	90-100	10-100KW	60%
Phosphoric acid	150-200	400KW	40%
Molten carbonate	600-700	300KW-3MW	45-50%
Solid oxide	700-1000	1KW-2MW	60%

1.2 Low Emission Engines:

Battery Electric Vehicle: A Battery Electric Vehicle (BEV) is an electric vehicle exclusively powered by an electric battery, eliminating the need for an internal combustion engine. These vehicles utilize lithium-ion batteries to store and supply energy to an electric motor, resulting in zero tailpipe emissions and an environmentally friendly operation. BEVs have become increasingly popular as a sustainable substitute for conventional gasoline-powered vehicles, presenting benefits such as reduced operating costs, diminished air pollution, and a decreased reliance on fossil fuels. Ongoing advancements in battery technology are enhancing the range and affordability of BEVs, further driving their widespread adoption in the automotive industry.

1.2.2. **Range Extender Electric Vehicle:** A Range Extender Electric Vehicle (REEV) is an electric vehicle fitted with an additional power source, usually a small internal combustion engine or a fuel cell, serving as a generator to recharge the vehicle's battery. In contrast to traditional hybrid vehicles, REEVs predominantly run on electric power, utilizing the range extender to supply extra electricity when necessary. This design enhances the vehicle's driving range, addressing concerns about "range anxiety" often associated with fully electric cars. The range extender activates when the battery's charge is low, providing added flexibility and positioning REEVs as a potential transitional technology toward fully electric transportation.

1.2.3. **Plug in Hybrid electric vehicle**: A Plug-in Hybrid Electric Vehicle (PHEV) is a flexible car with both an internal combustion engine and an electric motor, featuring a larger battery that can be charged by plugging into an outlet. This allows for short all-electric trips, and when needed, the internal combustion engine takes over for longer distances. PHEVs offer benefits like lower fuel consumption and reduced emissions during electric operation, serving as a bridge between traditional and fully electric vehicles.

1.2.4. **Bio diesel engine:** A biodiesel engine is an internal combustion engine that operates on biodiesel fuel, derived from renewable sources like vegetable oils, animal fats, or recycled cooking oils. These engines are designed to work seamlessly with traditional diesel engines, often requiring minimal modifications. Biodiesel, known for its lower environmental impact and reduced reliance on fossil fuels, is considered a more sustainable option. Biodiesel engines contribute to eco-friendly transportation by providing a renewable alternative within the existing diesel infrastructure. Ongoing research aims to enhance efficiency and broaden the application of biodiesel engines in diverse settings.

Table 2-Comparison between low emission engines

FUEL	**EFFICIENCY**	**CARNOT**	**RATIO**
PETROL	51.7%	89.8%	57.6%
HYDROGEN	52.3%	90.7%	58.8%
ETHONAL	52.03%	90.2%	58%
METHANE	52.9%	90.5%	58.5%

Formulae:

1. **Efficiency=**$\frac{Total\ useful\ energy}{Input\ energy}$***100**

2. **Carnot=1-**$\frac{T_C}{T_H}$***100**

Where T_C is typically the ambient temperature or the lower operating temperature of the engine.

Where T_H is the temperature of the engine's combustion chamber.

3. **Ratio**=$\frac{Power\ delivered\ by\ fuel\ cell\ stack}{Total\ power\ out\ put\ of\ the\ power\ train}$

2. EMISSION REDUCING TECHNOLOGY

2.1. Carbon Capture and Sequestration:

Carbon Capture and Sequestration (CCS) is a technology designed to mitigate greenhouse gas emissions from industrial processes and power generation. It involves capturing carbon dioxide (CO_2) emissions produced by facilities like power plants and industrial plants before they are released into the atmosphere. The captured CO_2 is then transported and stored underground in geological formations, such as depleted oil and gas fields or deep saline aquifers. CCS plays a crucial role in reducing the carbon footprint of high-emission industries, contributing to global efforts to combat climate change by preventing the release of CO_2 into the atmosphere. Despite its potential, challenges such as high costs and infrastructure requirements remain, and ongoing research aims to optimize and advance CCS technologies.

2.2. Clean Energy Sources for Hydrogen Production:

Producing hydrogen using clean energy sources focuses on utilizing renewable resources with minimal environmental impact. This involves methods like electrolysis powered by renewable electricity from solar or wind energy, biomass conversion processes, and tapping into geothermal energy. These eco-friendly approaches align with the broader goal of reducing carbon emissions and fostering a more sustainable energy landscape.

2.3. Fuel Cell Efficiency and Emission Reduction:

Fuel cell efficiency and emission reduction are pivotal in green energy technology. These cells convert hydrogen into electricity through electrochemical processes, providing high efficiency and minimal emissions. As they generate power without combustion, fuel cells contribute significantly to lowering air pollution and greenhouse gas emissions. Due to their efficiency and eco-friendly operation, fuel cells hold promise for clean energy applications in both transportation and stationary power generation. Continuous research seeks to optimize fuel cell efficiency, advancing their use for a more sustainable energy landscape.

Table 3-Comparison of pollutants:

Pollutants	**Source**	PM_{10}	SO_2	CO_3	O_3	NO_2
STATISTICS (PSI)	**Mladen Korunoski et al. [11]**	**24-hour average ($\mu g/m^3$)**	**24-hour averages (PPG)**	**8-24 hour period (PPM)**	**Maximum 24 hour period (PPB)**	**Maximum 24 hour period (PPB)**
50		50	30	4.5	60	-
100		150	140	9	120	-
300		420	600	30	400	1200
500		600	1000	50	600	2000

PPM- part per million.

PPB- Part per billion.

PSI-Pollution standard index.

Conclusion:

In summary, the integration of low-emission engines into hybrid electric vehicles marks a significant stride towards a greener and more sustainable transportation landscape. By marrying internal combustion engines with electric propulsion, these engines effectively tackle challenges associated with air quality and greenhouse gas emissions. The hybrid configuration not only enhances fuel efficiency but also minimizes tailpipe emissions, showcasing its potential to elevate overall vehicle efficiency. With ongoing technological advancements, it is clear that low-emission engines in hybrid electric vehicles are pivotal in advancing cleaner transportation solutions, aligning with global efforts to address climate change and enhance the overall sustainability of the automotive industry**.**

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