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Biofuels and Gaseous Fuels in Diesel Engines to Mitigate Energy Crisis and Climate Change

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ABSTRACT :

In the 21st century, the world faces interconnected challenges that threaten both environmental sustainability and energy security. The dual crises of escalating energy demand and accelerating climate change necessitate urgent and innovative solutions. Biofuels, derived from biomass sources such as agricultural residues, algae, and dedicated energy crops, offer a renewable and potentially carbon-neutral alternative to conventional fossil fuels. Unlike fossil fuels, biofuels can be produced domestically, reducing dependence on imported oil and enhancing energy security. The current paper sets the stage for a comprehensive exploration of biofuels and gaseous fuels in diesel engines within the context of the energy crisis and climate change. This paper explores the potential of biofuels and gaseous fuels in diesel engines as promising avenues to address these pressing issues. The study also outlines the rationale, objectives, and significance of the study while emphasizing the urgency of transitioning towards sustainable energy solutions.

Keywords: Biofuels; Climate change; Diesel engine; Emission; Performance

1.Introduction :

The global energy landscape is undergoing significant transformations marked by a growing energy demand, dwindling fossil fuel reserves, and concerns over greenhouse gas (GHG) emissions. Fossil fuels, which have long been the cornerstone of global energy supply, are finite resources that contribute substantially to atmospheric concentrations of carbon dioxide (CO_2) and other pollutants, exacerbating climate change[1]. The Intergovernmental Panel on Climate Change (IPCC) has underscored the need for rapid and substantial reductions in GHG emissions to limit global warming to manageable levels. Simultaneously, the energy crisis manifests in volatile fuel prices, geopolitical tensions over resource control, and the challenge of providing reliable and affordable energy access to all populations. The imperative to diversify energy sources and promote sustainable alternatives has never been more urgent.

Furthermore, biofuels have the potential to significantly mitigate GHG emissions, particularly when considering the life cycle impacts of their production and utilization [2]. The integration of biofuels into diesel engines, either through blends with petroleum diesel or as pure biodiesel (B100), presents a viable pathway to reduce emissions of particulate matter, nitrogen oxides (NO_x), and carbon monoxide (CO). Moreover, ongoing research focuses on optimizing engine performance and durability while ensuring compatibility with existing infrastructure and vehicle fleets [3].

Biofuels, derived from renewable biomass sources, offer a promising alternative to traditional fossil fuels in diesel engines. Their utilization helps reduce GHG emissions and enhance energy security. Biodiesel is perhaps the most widely adopted biofuel for diesel engines. It is produced from various feedstocks such as vegetable oils (soybean, rapeseed, palm, etc.) and animal fats through a process called transesterification [4]. Biodiesel can be used in pure form (B100) or blended with petroleum diesel in different ratios (e.g., B20, B5). Biodiesel is compatible with existing diesel engines and infrastructure, requiring little to no engine modifications [5]. It typically reduces particulate matter (PM), CO and unburned hydrocarbons (UHC) emissions compared to petroleum diesel. Being derived from plants and animal fats, biodiesel contributes to reducing reliance on finite fossil fuel resources. The different emission norms followed by different countries are shown in figure 1.

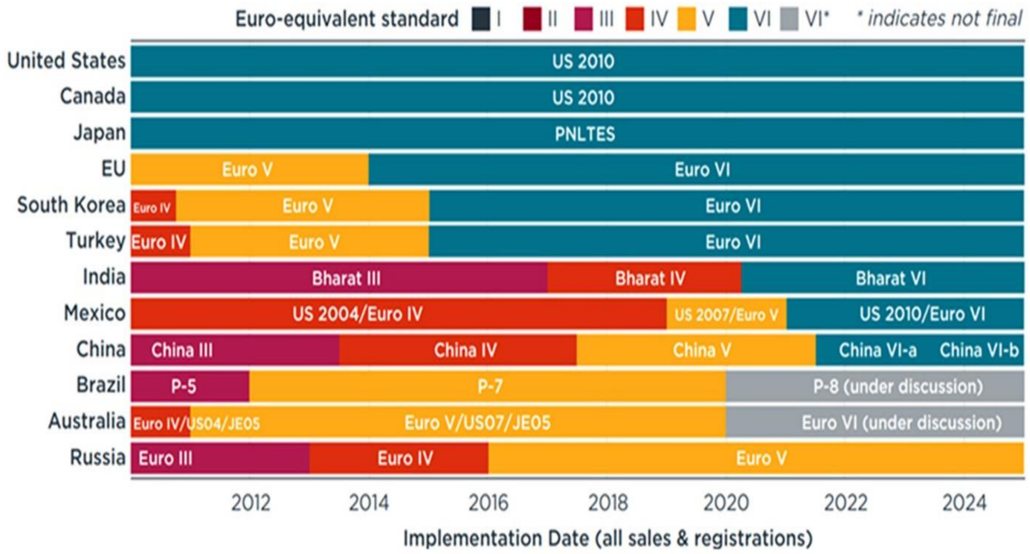


Fig. 1. Emission standard of different countries [6]

In parallel, the utilization of gaseous fuels such as compressed natural gas (CNG) and liquefied natural gas (LNG) in diesel engines offers another promising strategy. Natural gas is cleaner burning compared to diesel fuel, emitting lower levels of particulate matter and NO_x, and virtually no sulfur dioxide (SO_2) [7]. This transition not only reduces emissions but also diversifies fuel sources, leveraging abundant natural gas reserves in many regions. Adapting diesel engines to run on gaseous fuels requires modifications to fuel injection systems and combustion processes to optimize performance and efficiency [8]. Research efforts focus on addressing technical challenges, such as compression ratios, ignition timing, and storage considerations, to maximize the environmental and economic benefits of this transition [9]. The major area of dual fuel mode operation of the past research work was focused on below points:

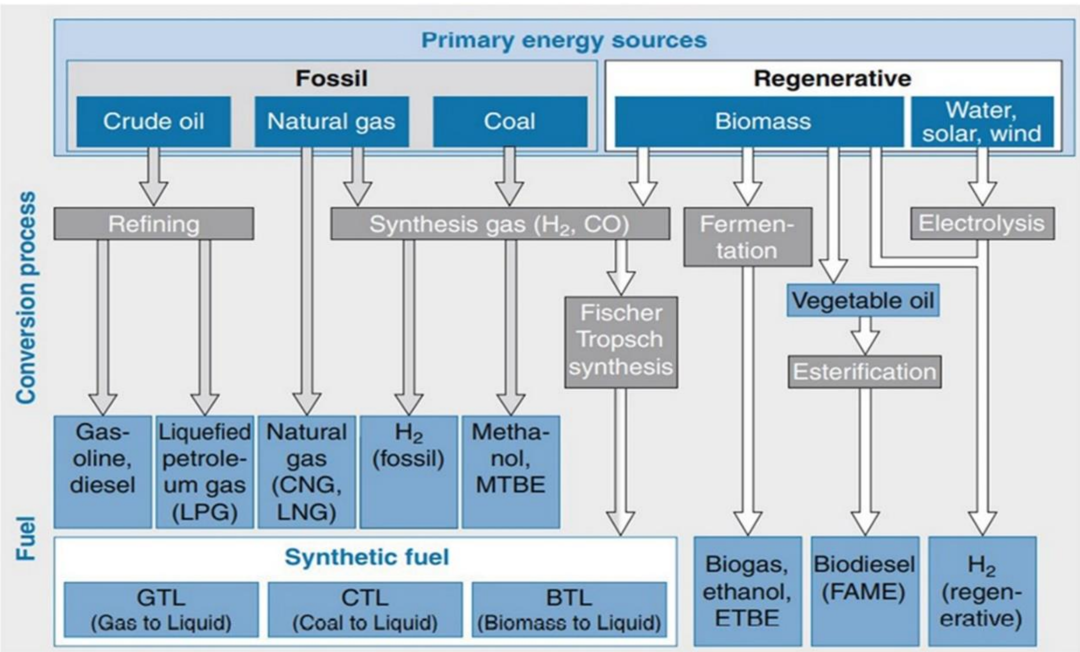
- Evaluating the environmental impacts of biofuel blends and gaseous fuels in diesel engines, including emissions reductions and energy efficiency gains.
- Assessing the economic feasibility and scalability of biofuel and gaseous fuel adoption in different geographical and industrial contexts.
- Reviewing technological advancements and regulatory frameworks that facilitate the widespread adoption of these alternative fuels.
- Proposing recommendations for policymakers, industry stakeholders, and researchers to accelerate the transition towards sustainable energy solutions.

Based on the above discussion, the aim of the current paper is to critically analyze the efficacy of biofuels and gaseous fuels in diesel engines as sustainable alternatives to mitigate the energy crisis and combat climate change.

2. Biofuels

There are many benefits of using biofuels in internal combustion (IC) engines. Renewable diesel, also known as green diesel or hydrotreated vegetable oil (HVO), is chemically similar to petroleum diesel but produced from renewable feedstocks [10]. It undergoes a hydrotreating process that removes oxygen and sulfur, resulting in a cleaner-burning fuel. Renewable diesel has a high energy density and can be used as a drop-in replacement for petroleum diesel, offering similar engine performance. It typically produces lower levels of particulate matter, NO_x, and carbon dioxide emissions compared to conventional diesel[11]. The different primary and alternative energy sources are shown in figure 2.

Fig.2. Alternate energy source



Biogas is produced through anaerobic digestion of organic waste materials such as agricultural residues, food waste, and sewage. When purified to remove impurities like carbon dioxide and hydrogen sulfide, it becomes biomethane, which can be used as a gaseous fuel in diesel engines after compression. Biomethane combustion produces lower emissions of PM and NO_x compared to diesel engines. Utilizing biogas and biomethane from organic waste streams promotes waste valorization and reduces methane emissions from landfill sites. Bioethanol is primarily used in spark-ignition engines (gasoline engines) but can be blended with diesel fuel in small percentages (e.g., E10, E20) for certain applications. Its use in diesel engines is less common compared to biodiesel but has been explored in niche applications. In small blends, bioethanol can improve the cetane number of diesel fuel, aiding in combustion efficiency. Ethanol blends can contribute to lower particulate matter emissions and reduced GHG emissions compared to pure diesel fuel. The availability and sustainability of feedstocks for biofuel production are critical considerations. While most biofuels are compatible with conventional diesel engines, some blends may require engine modifications or adaptations. The availability of distribution infrastructure for biofuels, such as blending facilities and storage tanks, may limit widespread adoption [12].

3.Dual fuel mode operation

Dual-fuel combustion modes, such as diesel-LNG, could be used in heavy-duty truck applications, according to the researchers, while diesel-CNG and diesel-LPG could be used in passenger cars and light-duty vehicles. With approximately the same fuel conversion efficiency, this contributes to the improvement of CI engines' CO_2, NO_x, and PM emissions. Due to the combustion of heavier hydrocarbon fractions and lower carbon-to-hydrogen ratios than in conventional fossil fuel lean-burn conditions, the outcomes revealed a trade-off between NO_X and HC emissions. Therefore, exhaust gas after-treatment devices could be used to control PM and NO_x in order to comply with global emission regulations. The extremely low density-specific volume of LNG and CNG fuels at ambient temperatures is one major issue. The fuel injection system is impacted by this, and a fuel injector's cross-sectional area must be significantly larger than that of a diesel injector in order to inject the desired fuel mass.

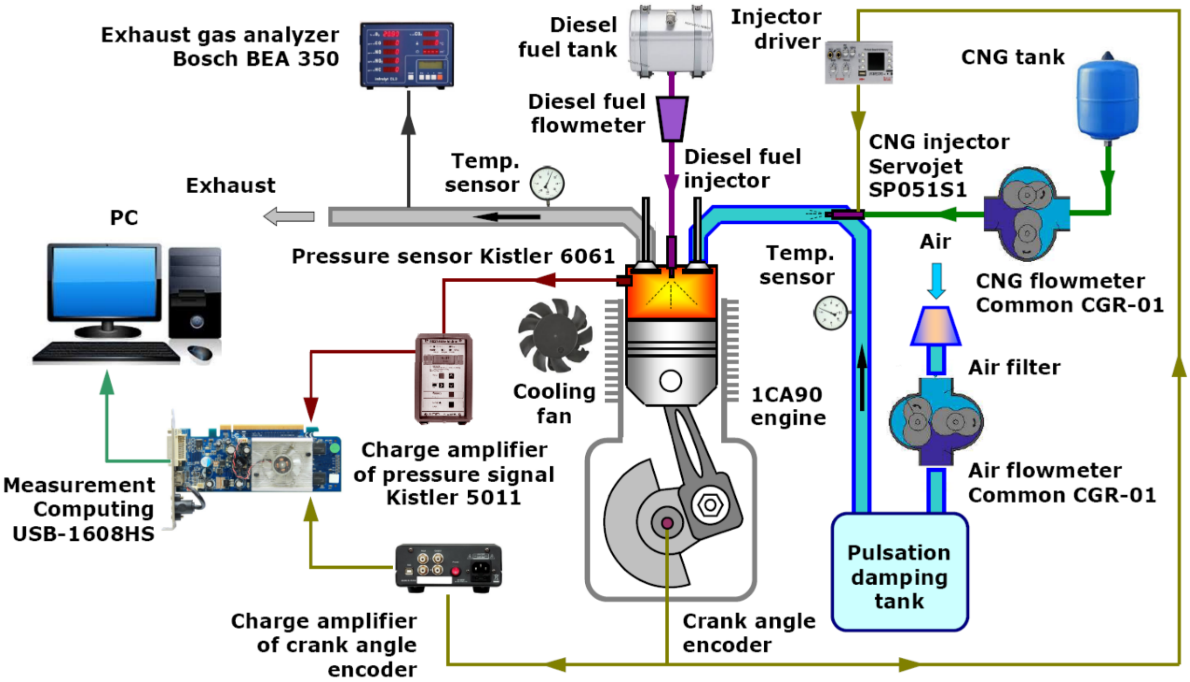


Fig. 3. Duel fuel mode engine operation [13]

High-pressure direct injection (HPDI) systems for diesel and CNG/LNG have recently demonstrated their suitability for high torque/horsepower applications made possible by the improved dual-fuel technology. The pilot diesel injection came after the main natural gas injection in the early stages of HPDI technology development. In order to implement more complex strategies for both the premixed and diffusion combustion models of these fuels, a more recent version of HPDI technology has been developed that can run on either saturated or unsaturated fuel [14]. As a dual fuel for conventional compression ignition engines, hydrogen has a number of advantages over other alternative fuels in terms of its combustion parameters and effects on the environment, including lower CO, CO_2, and HC emissions and lower costs. Different examinations have been led to involve hydrogen as fuel in IC motors [15].

Due to the higher diffusivity of biogas, the formation of homogeneous charges, and the substitution of high carbonaceous fuel, the biogas induction also reduces smoke emission and soot production [16]. The improper combustion of a rich F/A mixture typically results in the emission of PM or smoke. Fuels with a low hydrogen-to-carbon (H/C) ratio produce more smoke. The H/C ratio of diesel fuel is lower than that of biogas; As a result, smoke/PM levels are high, in contrast to the biogas-DF engine system. The absence of sweet-smelling composites in biogas likewise brings down the smoke darkness for biogas-DFM. However, due to the low combustion temperature, the smoke increased with increasing BFR. The variety of smoke discharge with BFR was displayed. Due to its higher O_2 content, which enhances combustion, the use of biodiesel as a secondary fuel may further reduce smoke emissions. The advancement in IT also reduces smoke emissions and improves combustion rate and oxidation in the combustion chamber [17]. Moreover, the expansion in CR likewise diminishes the smoke discharge by short ID and higher ignition temperature prompting further developed burning and oxidation qualities [18]. The use of hydrogen in dual fuel mode is shown in figure 4.

This literature review makes it abundantly clear that natural gas—primarily composed of methane CH_4 is one of the alternative fuels with the greatest potential for use in transportation. Due to its higher H/C ratio among all hydrocarbons, it reduces NO_X emissions and naturally lowers CO_2 emissions [19]. Researchers looked into how diesel and dual-fuel sprays, which used dodecane to ignite lighter methane-air mixtures, sprayed. As depicted in Figure, dual-fuel ignition is a volumetric process with five stages. The two-phase spray with high velocity is the result of the first stage. The length of the liquid penetration and the amount of liquid fuel that evaporated at this stage were determined by the FIP and the fuel's thermodynamic properties [20]. Similar to the first stage, the second stage involved the ignition or activation of various intermediate species and radicals through low-temperature chemistry (LTC) [21].

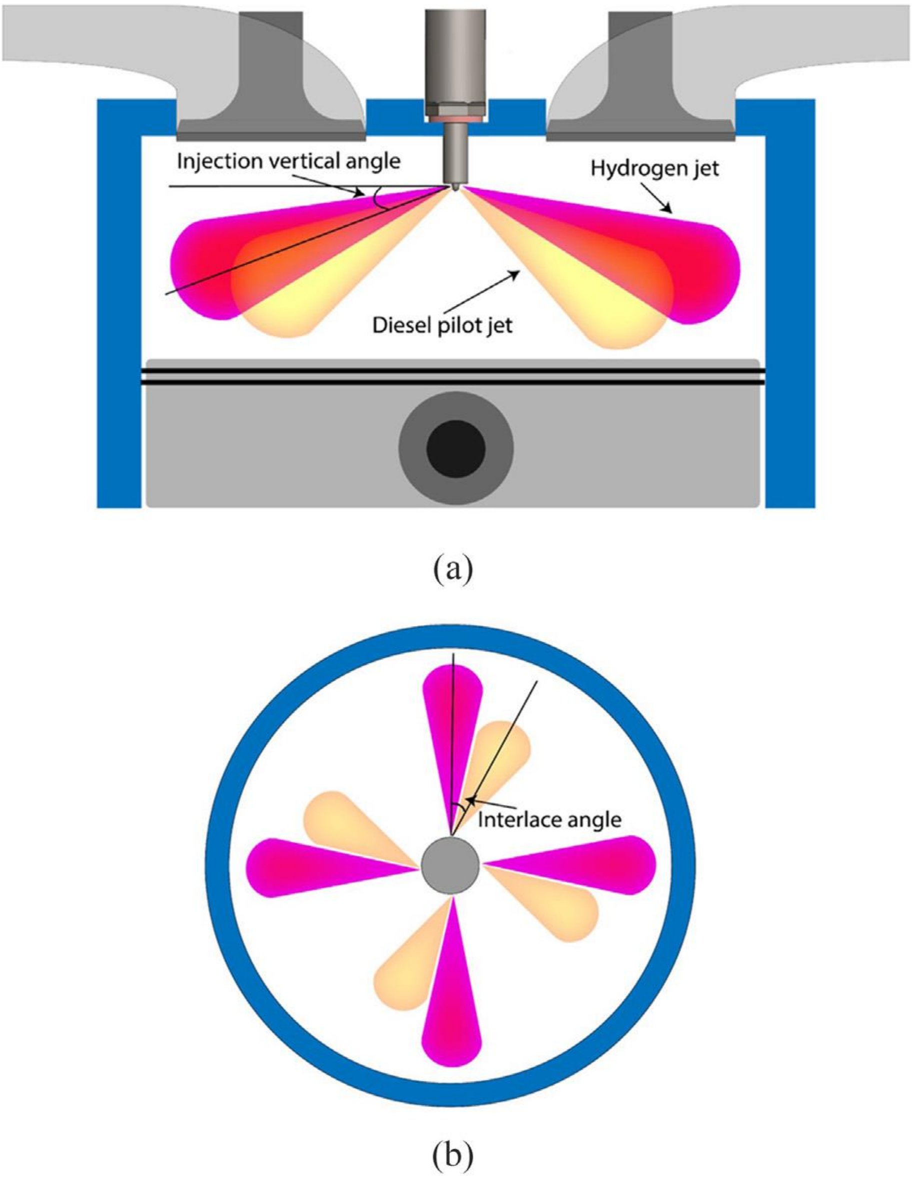


Fig.4 Hydrogen in dual fuel mode operation

4. Conclusion :

Biofuels offer a versatile range of options for reducing greenhouse gas emissions and enhancing energy security in diesel engines. Their adoption depends on technological advancements, policy support, and sustainable feedstock management to realize their full potential as a sustainable alternative to fossil fuels. Continued research and development are essential to overcome challenges and promote the wider use of biofuels in diesel engines globally. Understanding the potential of biofuels and gaseous fuels in diesel engines is crucial for achieving sustainable development goals and addressing global energy challenges. By promoting cleaner fuels and reducing dependency on fossil fuels, this research contributes to enhancing energy security, mitigating climate change impacts, and fostering a more resilient and equitable energy future for generations to come.

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