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Comprehensive Review of Efficiency Enhancement Techniques for Dual-Fuel Compression Ignition Engines with and without Nano-Additives

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Abstract: Currently, hydrogen gas is being used in several applications and its impact during combustion, using with & without additives and hydrogen blends modified dual fuel engine, especially for combustion and energy generation purposes due to its chemical features. Furthermore, the flame speed and calorific value render hydrogen highly suitable for diesel engines. The trends in vehicle engine design and development have shifted toward the replacement of advanced and efficient fuels. The existing patterns of injections, the innovations in diesel engines, and the prospects of using them for increasing engine effectiveness are all analyzed. The incorporation of H_2 as a secondary fuel in DE is under scrutiny. This is done by varying the speed of the engine along with controlling the amount of hydrogen burnt for heat and power. This paper aims to establish appropriate conditions for the application of hydrogen as an additional fuel without neglecting the environmental impacts or the efficiency of the engine. These studies can potentially lead to the development of advanced means of transportation that are both efficient and environmentally friendly. To understand the more holistic environmental impacts, this research will also analyze emissions produced by hydrogen when used as an auxiliary fuel in a diesel engine. This work aims to minimize dependence on fossil fuels by transforming vehicles and powering them, and also identifies that the nano additive in dual fuel (hydrogen-Disel fuel) enhances the maximum efficiency and reduces harmful emissions. These studies can lead to the development of transportation means that are both sustainable and effective. In order to lessen the effects on the atmosphere, the research will also analyze the emissions when hydrogen is applied as an auxiliary fuel. It is expected that the results of this study will help transform vehicle power systems while greatly decreasing the use of traditional fossil fuels.

Keywords: Emissions, CRDI (Common rail direct injection), Nano Additives, Hydrogen Fuel.

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1. Introduction

An internal combustion engine produces energy from three elements: energy used for productive work, energy lost through the coolant system, and energy lost through the exhaust system [1]. Only one-third of all energy is consumed within the body and released as work. As a result, an internal combustion engine operates more efficiently and performs better by utilizing heat losses as a level of usable work. That being said, these thermal barrier coating materials are also formed to create a reduced transfer of heat to increase the efficiency of an IC Engine (internal combustion engine) and have been used to enclose the piston, cylinder head, combustion chamber, as well as the inlet valve [2]. Of all types of vehicles, automobiles and other carbon-emitting vehicles are among the most prolific pollutants, releasing over 24 percent of CO_2 into the atmosphere. There is a growing push for greener means of transportation in order to reduce this impact. Cleaner private autos and greater promotion of active and public transport will be required to achieve this goal. This will require cleaner private cars as well as continuing to promote active and public transport [3]. Great research is being done on alternative fuels due to the energy shortage and vehicle emissions pollution. There is intensive research and usage of alternative fuels in transportation, such as natural gas, methanol, ethanol, and biodiesel [4]. Conventional fuel for CI engines is injected over a DI towards the end of the CS, when the temperature of the fuel is much lower than that of the charge after the air has been compressed. This initiates combustion, which causes a flammable mixture of fuel and air within the cylinder to combust and produce energy for the engine. Air and producer gas combined are dubbed the charge mixture and are normally used for dual-fuel diesel engines. A high-speed diesel injector sprays a little bit of regular fuel into this compressed charge mixture, where it diffuses into the rest of the cylinder [5]. Many experts state that natural gas is one of the most efficient fuels. It is easy to mix with air, contains no carbon, and is an efficient use of energy. Moreover, natural gas, when burned, emits fewer pollutants than other fossil fuels, which is why we consider NG to be cleaner. Hydrogen gas is one of the most important gases used in the energy production scheme today due to its wide range of chemical characteristics, allowing for multiple events like combustion. Methods of creating hydrogen gas range from electrolysis to renewable feedstocks. This has increased hydrogen's potential as a future source of secure, clean, and reliable energy. But hydrogen currently makes up only about 3% of global end-use energy.

The top four challenges are: (1) the incongruity between hydrogen production sites and demand, (2) transportation cost (at a small volume), (3) the nonexistence of substructure for the storage, transmission, and use of hydrogen, and (4) the cost of constructing pure hydrogen pipelines that will enable widespread hydrogen use. Excess electricity can be utilized to produce H_2 via electrolysis [6]. This hydrogen can then be stored and transported to regions where energy is in high demand, acting as an enabler for production and consumption. Moreover, Storage Next generation state of the art technologies for the storage and transportation of hydrogen, such as solid-state storage materials and vehicles for hydrogen fuel cells, are creating solutions to infrastructure challenges and lowering costs [7]. Another advantage of hydrogen is that it can be built on existing heating infrastructure that runs on natural gas in buildings. For the complete greenization of all land, air, and sea transportation, the hydrogen-fueled internal combustion engines and fuel cells, along with battery electric vehicles, are used. Since the first investigation, more studies have been conducted regarding the usage of hydrogen-methane mixtures in internal combustion engines (IC engines)[8]. A demand-driven hydrogen production control method for an internal combustion engine is proposed [9]. Studies have also been performed that look at the viability of incorporating hydrogen fuel into heavy-duty, long-haul internal combustion engine buses [10]. Free of sulfur, making them a cleaner substitute for diesel fuel. They are also exploring the feasibility of hydrogen internal combustion engines by 2030 [11]. Reviewing advancements in modeling, in-cylinder heat transfer, and combustion processes gives a perspective on the potential for direct H_2 injection ICEF [12]. In order to make these other fuel types more accessible and affordable to consumers, the development of new technologies and infrastructure is critical [13]. The opportunity lies in researching and investing more in these transportation systems and making it a sustainable, environmentally friendly future [14].

2. Related Work

In the field of IC engines, there’s growing interest in the use of hydrogen in DF systems. The Assessment and Hydrogen feasibility as a substitute fuel in dual-fuel combustion to achieve carbon-free combustion and decrease emissions has been examined. In previous work, the many factor analysis the sustainability and environmental impact of mixing hydrogen with other fuels, such as diesel [15]. However, the liquid petroleum gas (LPG) can decrease emissions and fossil fuel consumption. Natural gas is a pertinent option for reducing engine errors like knocking and other instability [16]. So, it has been observed that the technology of dual-injection may be applied in spark ignition engines to enhance the efficiency of renewable fuel use. Several fuel combinations, such as hydrogen and alcohol, have been studied to capitalize on the unique properties of each fuel and improve engine performance [17]. On the other hand, the experimental results identified that mixing hydrogen gas with biodiesel in a dual-fuel engine arrangement increases combustion and performance while decreasing pollution levels compared to single-fuel operation. This is attributed to the high cetane number of H_2 (hydrogen), which enhances ignition and combustion efficiency. Besides, the presence of hydrogen can help minimize particulate matter emissions in the exhaust.

2.1 Injection of ICE

The fuel injector system plays a key role in an internal combustion engine. By breaking the fuel into tiny particles and injecting it at high pressure, so research gaps the system ensures efficient combustion. Diesel engines rely on different types of fuel injection methods, and both injection timing and technique play a crucial role in how well the engine performs and how much pollution it produces. Despite these results on how various fuels and injection techniques affect compression ignition engines, pointing to improve efficiency and lower emissions. In previous researcher investigated the biofuel influence on the optimization and emissions of CI engines, focusing on the usage of a CR injection system and various fuel blends [18]. Similarly, conducted emissions investigations with different fuels under varied SF injection timing settings in a single cylinder DI diesel engine, revealing insights into NO_x emissions of alternative diesel fuels [19]. Likewise, they researched the CI of directly injected natural gas and the DF performance of compression ignition diesel engines, shedding light on gaseous FI in compression ignition engines [20]. Also, optimization of injection systems has been investigated. Studies examined the impacts of injection rate shape and start-of-injection-based software optimization on DE combustion and emission performance, confirming the importance of injection management for engine efficiency and emissions [21]. Further study focused on the fuel compensation control of high-pressure diesel engine utilization in common-rail, with an emphasis on advances in high-pressure common-rail diesel injection systems. Additionally, the impact of several parameters on injection performance has been investigated. The impacts of fuel temperature on the injection performance of an electronic unit pump (EUP) system [22] were investigated, with a focus on the impact of fuel temperature on injection characteristics [23].

2.2 Throttle Body Injection

The TBI system is an important part of internal combustion engines, controlling air-fuel mixture delivery and combustion. It controls the flow of air into the engine, influencing the combustion process. Research on the engineering fundamentals of internal combustion engines sheds light on the CP (combustion process) and the role of the throttle body injection system in fuel delivery to the engine [24]. Added to that, as integral components of modern FI systems, such as TBI systems, the study emphasizes the need of constancy analysis and disorder control in electronic throttle dynamical systems [25]. The principal function of a throttle body assembly is to control engine airflow in response to vehicle demand. A throttle body assembly's principal function is to control engine air flow in response to vehicle demand. The TB is located in the area between the intake manifold and the air cleaner. A venturi is used to reduce the air pressure that passes through it. The input flow can be lowered by decreasing the flow area. This is performed by installing a throttle shaft, a circular shaft downstream of the vent that is outfitted with a butterfly valve. In addition, the implementation of the EOQ and Lambert W function in engine simulation models emphasizes the importance of effective fuel delivery systems, such as throttle body injection, in optimizing the fuel injection system in GDI engines, as discussed previously [26].

2.3 Multi-Point Injection (MPI)

Because hydrogen has the potential to reduce emissions and boost efficiency, its usage in (ICEs) has sparked a lot of interest. When considering the use of hydrogen in internal combustion engines (ICEs), multi-point injection systems raise concerns about pressure levels and injector flow rates. Research has shown that hydrogen direct injection in SI internal combustion engines (ICEs) can obtain improves power of engine output and efficiency while emitting low levels of pollution [27]. A multi-point fuel injection system can fuel an internal combustion engine through many ports on each cylinder's intake valve. These apertures work together to supply the proper amount of gasoline to each cylinder at the right time. MPFI units are available in three configurations: sequential, simultaneous, and batched. The first type of multi-point fuel injection system delivers gasoline to the cylinders in batches through the ports; the intake strokes are uncoordinated. In sequential MPFI systems, fuel is released at the same time as each engine cylinder's intake stroke, whereas in simultaneous MPFI systems, fuel is released into every engine cylinder simultaneously. The shortage of literature on multi-point hydrogen injection utilized with natural gas engines suggests a potential topic for future research and development. [28]

2.4 Common Rail Direct Injection (CRDI)

Many studies have been undertaken on the (CRDI) system in diesel engines, with a focus on the analysis of the combustion behavior. The injection effect settings on combustion and emissions in a CRDI diesel engine powered by biodiesel derived from spent cooking oil were investigated. The learning elaborates on the impact of the method of injection on the biodiesel

Nitrogen oxide result, utilizing a common rail turbocharged direct injection diesel engine at moderate speed and load. Additionally, the injector pressure, start rate, and duration improve the engine performance and lower emissions [29]. According to research, it was found that using CRDI technology in diesel engines improves combustion and emissions. CRDI technology can be used to manage fuel injection limitations such as fuel injection pressure, start of injection (SOI) timing, fuel injection rate, and injection duration [30].

2.5 Ignition Delay Time

Numerous studies identified the factor in defining fuels as the ignition delay time (IDT). In fundamental research, IDT is a common validation target that is used to gauge how well suggested chemical kinetics procedures work. [31].Extensive research on the researcher IDT of NH_3 has been conducted since the 1960s, and in the last five years, various new research works on ammonia and ammonia/fuel blends have been published. The most relevant IDT research up to 2020 has been concisely described. More research on the IDT of ammonia/fuel blends has been published in the previous two years, providing a broader range of data sets and unique blending choices for engine-relevant state [32]. Over the past decade, the review essay has also highlighted the implications of the chemical kinetics and thermodynamics involved in ammonia combustion. This info is serious for improving engine performance and lowering emissions in future sustainable transportation systems.

2.6 Natural gas in IC engines

Natural gas is globally recognized as an important substitute fuel for internal combustion engines. It is regarded and energy efficient alternative to auxiliary fuels. Natural gas offers numerous obvious and beneficial advantages over other alternative fuels, including reduced capital costs and lower greenhouse gas emissions. Table 01. summarizes the properties of natural gas. However, it is concluded that the high-octane number of the natural fuel, it can be employed in diesel engines with high CR. In recent years, governments around the world have paid increased attention to natural gas as a fuel option for all IC engines used in power generation and industrial applications due to energy scarcity and pollution. This is due to fresh air being mixed with natural gas directly into the intake manifold or cylinder, followed by a similar mixture that is burnt through a spark plug or pilot diesel fuel. This method allows for more efficient burning of the fuel combination, resulting in more power production and lower emissions. Investigated the previous studies, the natural gas can also assist lessen addiction to traditional petroleum-based fuels. So, analyze the combustion efficiency enhancement and emission reduction by applying these strategies, dual-fuel systems, and auxiliary fuel development since the 1950s. In light of the following investigation, the dual fuel provides high octane and has an impact on the economics and environmental benefits. A considerable amount identified that the use of natural gas and diesel fuel in engines can lower emissions of hazardous pollutants such as NO_x (nitrogen oxides). In addition, the utilization of dual-fuel technology might result in cost savings for operators because natural gas is less expensive than diesel fuel. In practice, life the retrofitting bus engines with dual fuel kits that replace some of the diesel fuel with natural gas can help reduce methane emissions from heavy-duty transportation [33]. Furthermore, dual-fuel technology in marine engines, such as replacing diesel with LNG, has been shown to enhance ecological features and reduce environmental effects. Researchers have investigated many aspects of dual fuel combustion, including fuel blend optimization and injection technique development. For example, studies have examined how various fuel combinations, such as ethanol and gasoline, alter the way dual-fuel engines burn. Recent research has focused on building dual-injection spark ignition engines with adaptable fuel injection systems. The environmental and cost effectiveness of dual fuel propulsion solutions, particularly those fueled by natural gas, have been assessed for applications such as LNG carriers. By providing the useful feedback from the previous research to improve total system efficiency, dual fuel technology could be combined with other good technologies, such as the excess HR of ORC for in marine engine by the use of natural gas in dual fuel systems has the potential to improve combustion efficiency, reduce emissions, and improve overall environmental sustainability in a diversity of industries, including transportation and maritime [34]. Dual fuel systems can considerably reduce hazardous emissions like nitrogen by using natural gas as a cleaner-burning fuel source in addition to regular diesel or gasoline. Dual fuel systems can dramatically reduce hazardous emissions such as nitrogen oxides and particulate matter by combining natural gas as a Purifying-burning fuel source with regular diesel or gasoline. This investigation into a source of energy utilization helps to spread fuel options and minimize reliance on fossil fuels.

Table 01 Configuration and Properties of Natural Gas

CONSTITUENT	V/V (%)	CONSTITUENT	V/V (%)
CH_4	91.72	C_5H_{12}	0.03
C_2H_6	5.5	N_2	0.322
C_3H_8	1.98	CO_2	0.03
C_4H_{10}	0.44	Lower Heating Value	49.51
DENSITY	0.788	Air/fuel Stoichiometric ratio	17.2

2.7 Using Ammonia in IC Engines

The performance characteristic of ammonia in CIE in DF (dual-fuel) mode with DE has continued to be a viable method to improve engine performance while lowering carbon emissions. The system tested by Measurement was used to explore the combustion properties of ammonia in ICE (internal combustion engines), particularly SIE (spark-ignition engines). According to the outcomes, ammonia burns well in SI engines and generates significant power outputs, especially when combined with hydrogen enrichment or increased intake pressure. Ammonia-hydrogen (NH_3+H_2) blends have been used in IC engines and found to enhance the efficiency and mean effective pressure, making them suitable fuels for SI engines. After the evaluation, the blends also have the potential to enhance the air quality because they have demonstrated promise in reducing emissions of dangerous pollutants like nitrogen oxides. Additionally, ongoing research is looking into the best blend ratios and combustion methods to optimize the benefits of using NH_3-H_2 (ammonia-hydrogen blends) in internal combustion engines. Experimental research [35] was completed on the combustion features of ammonia in internal combustion engines, particularly spark-ignition engines. The outcomes show that NH_3 burns competently in SI engines and harvests a sizable amount of power, particularly when paired with hydrogen enrichment or higher intake pressure. The system was tested by Ammonia hydrogen blends have been shown to increase efficiency and mean effective pressure in IC engines, which makes them suitable fuels for SI engines. Additionally, the ability to improve air quality by reducing harmful pollutants like nitrogen oxides [36]. Additionally, ongoing research is looking at the optimal combustion methods and blend ratios to optimize the compensations of using ammonia-hydrogen blends in IC engines. Ammonia processes have been transferred from diesel engines [37].

2.8 Hydrogen properties in IC engines

Table 2 indicates that hydrogen has distinct Characteristics when compared to the outdated fossil fuels usually exploited in transportation, notably compressed natural gas (CNG), gasoline, and diesel. Throughout the study, engine [38] performance in dissimilar engine methods using these fuels is regularly compared to that of hydrogen. The negligible carbon content of H_2 is one of the many compensations for it as a clean alternative fuel in internal combustion engines. After eliminating carbon-based pollutants such as CO, CO_2, and soot, Nitrogen Oxide (NOx) is the only harmful combustion byproduct left. The value of heating hydrogen is lower due to its high specific energy density, which allows it to offer nearly 3 times as much energy per mass as additional F. Fuel [39].

Table 02: A Property-based comparison of fuel

(^{a} at 1 inn., ^{b} at 273 K., c at 298 K., d at stoichiometry., ^{e} methane. ,^{f} vapor and ^{g} n-heptane.)

PROPERTY	HYDROGEN	CNG	GASOLINE	DIESEL
VOLUMETRIC ENERGY DENSITY ^{A,B} (MJ/M^{3})	10.7	33.0	33 × 103	**35 × 103**
LOWER HEATING VALUE (MJ/KG)	119.7	45.8	44.8	**42.5**
DENSITY OF FLUID FUEL^{A,B} (KG/M^{3})	0.089	0.72	730–780	**830**
STOICHIOMETRIC AIR/FUEL MASS RATIO	34.5	17.2 ^{e}	14.7	**14.5**
MASS-BASED COMPOSITION OF CARBON CONTENT (MASS %)	0	75^{e}	84	**86**
MOLECULAR WEIGHT	2.016	16.043 ^{e}	~110	**~170**
BOILING POINT ^{A} (K)	20	111 ^{e}	298–488	**453–633**
AUTO-IGNITION TEMPERATURE (K)	858	813 ^{e}	~623	**~523**
MINIMUM IGNITION ENERGY IN AIR ^{A,D} (MJ)	0.02	0.29	0.24	**0.24**
STOICHIOMETRIC VOLUME FRACTION IN AIR (%)	29.53	9.48	~2^{f}	**-**
DISTANCE OF QUENCHING ^{A,C,D} (MM)	0.64	2.1 ^{e}	~2	**-**
LAMINAR FLAME SPEED OF PROPAGATION IN AIR	1.85	0.38	0.37–0.43	**0.37–0.43 G**

^{A,C,D} (M/S)				
DIFFUSION COEFFICIENT OF AIR ^{A,B} (M^2/S)	8.5 × 10−6	1.9 × 10^{-6}	-	**-**
FLAMMABILITY (EXPLOSIVE) LIMITS IN AIR (VOL%)	4–76	5.3–15	1 – 7.6	**0.6–5.5**
COMBUSTION ADIABATIC TEMPERATURE $^{A.C.D}$ (K)	**2480**	**2214**	**2580**	**~2300**

2.9 Using hydrogen in spark ignition engines

There has been extensive research on the usage of the SI Engine of hydrogen. Fuels enriched with hydrogen have shown promising results in terms of increasing the evaluation efficiency and combustion parameters of spark-ignition engines. It was shown that adding peak pressure of hydrogen to gasoline while decreasing the pertinent crankshaft angle. The combination of hydrogen and ethyl alcohol also enhanced all engine performance characteristics in a gasoline spark-ignition engine. We evaluated the impacts of various spark plugs and hydrogen utilization in different engine loads, demonstrating the possibility of optimizing the performance of the engine with H_2-enriched gasoline. The procedure of hydrogen as a fuel additive in gasoline and diesel engines has also been investigated; the competence of the combustion process and the high cost of additional electrolysis facilities for hydrogen generation have been identified as limiting considerations [40]. Thus, examinations on the use of hydrogen in SI engines have shown that it has the potential to improve emissions, efficiency, and combustion. However, in order to fully profit from hydrogen-enriched fuels in spark ignition engines, challenges such as cost-effectiveness and combustion anomalies must be addressed.

2.10 Injection of Dual Fuels

The suction in a Combustion characteristic of a dual-fuel diesel engine is frequently a solution for generating gas and air, recognized as the CM. A high-pressure injector is used to inject a small amount of conventional fuel (Diesel) into the compressed charge mixture. This fuel then spreads to the nearby same mixture within the cylinder in a manner that is consistent with the spark ignition working condition [41]. Figure 4 depicts the intricate combustion process characteristic of dual-fuel and CI diesel engines, and pressure increases as a condition crank shaft angle position.

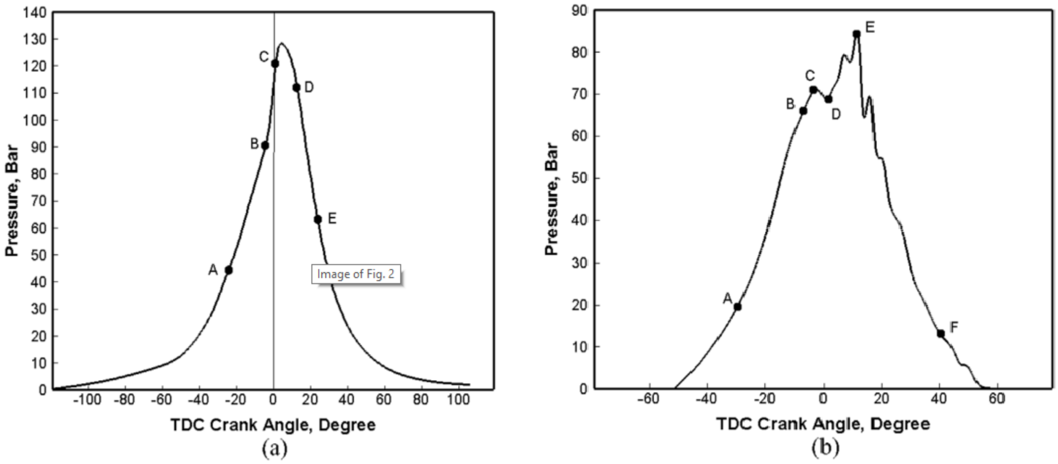

Fig. 4. Behavior of the combustion process, (a) for Conventional DE, and (b) DFE

Figure 4 shows the 4-stages of combustion in a Characteristic of CIDE, with Symbolizing (A-B) ignition delay, corresponding (B and C) to the premixed combustion phase, (C and D) assigned to the rate of regulated combustion phase, and (D and E) on behalf of the post combustion stage. The Process during the combustion of a dual-fuel diesel engine can be divided into five stages: A-B is the ignition delay, B-C is the pre-mixed combustion phase, C-D is the primary fuel ignition delay, D-E is the primary fuel uncontrolled combustion phase, and E-F is the post-combustion phase. When compared to normally aspirated mode, dual fuel engines have the longest ignition delay because the concentration of oxygen steadily decreases as we add the gaseous fuel. This decrease in oxygen concentration prolongs the ignition delay period. When the Saturation phase of combustion is considered, the diesel fuel mode demonstrates a higher rate of pressure increase. In comparison to typical diesel engines, new dual-fuel engines have a relatively short primary fuel igniting delay (C-D). Because the primary liquid fuel spontaneously ignites throughout the combustion period (D-E), it is also considered unstable. The nozzle and injector direction in dual-fuel diesel combustion mode were found to be crucial in optimizing the combustion process because they defined the interaction between the pilot fuel and gas jets. Figures 5 and 6 show a schematic of the axial cross-section and a top view of the dual-fuel DI jet configuration with a concentric injector. The injection angle is vertical between the cylinder head and the jet axis in the axial cross-sectional plane, whereas the intertwine angle is the angle between the diesel and gas jet axes of a circular injector in the top plane. As mentioned in Figure 5, the IA is rootless from the attached injector. It can be built as a parallel or converging array, depending on the injector design.

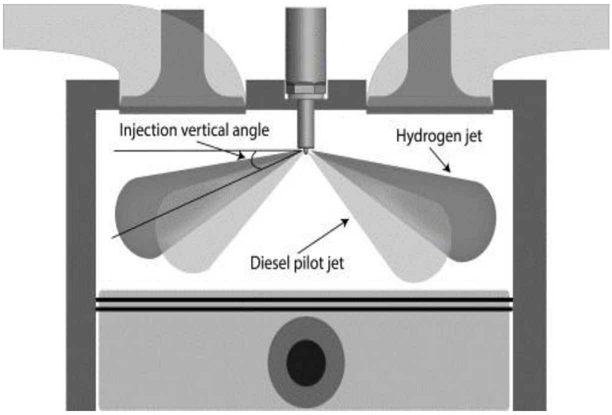

Fig. 5. Diagram of the CI jet vs. the axial cross-sectional plane

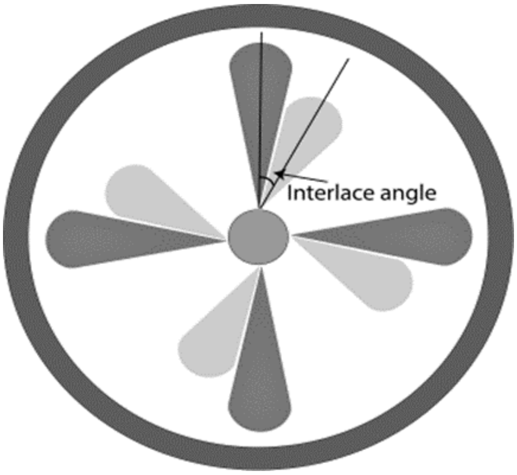

Fig. 6. Representation of the DFI concentric injector jet on the top plane

2.11 Nano Particle Additive in Dual Fuel Combustion Engine

Previous studies of Kumar et al. investigated that the nanoparticles/metal oxide enhance the efficiency of a dual fuel engine [42]. Al_2O_3 nanoparticles also improve the brake thermal efficiency in the diesel combustion system [43]. Parsad et al. identified that improving combustion stability and reducing fuel combustion [44]. Hydrogen dual fuel very significantly reduces the particle emission during the overall combustion cycle [45].

3. Effect of the Amount of Hydrogen on Diesel

The hydrogen used in this experiment was 99.99% pure. Diesel gasoline was a standard EN590-compliant convenience product. The FI advance for the examination of the engine was set to crank angle (22°) before TDC, while the injector of the hydrogen adjusts the intake stroke. While the engine was running at occupied load, the speed was set to RPM of (750, 900, 1400, 1100, 1750, and 2100) [46]. The engine map was established during pre-engine tests, and brake-specific DF consumption estimations were calculated using engine load and engine speed. The hydrogen energy component may thus be easily calculated due to the lower heating values of hydrogen and diesel fuels. To achieve the required hydrogen energy %, the injector's injection amount was simply adjusted based on the injection duration. The Mass flow rate H_2 between (12.5 and 44.6 slpm), depending on the input hydrogen energy portion and engine speed. The mass flow rate of the hydrogen was adjusted to be between 25% and 50% of the mixture's total energy.

4. Experimental Results

Figure 7(a) shows how the test engine's brake power changed with different hydrogen energy concentrations (0%, 25%, and 50%). Figure 7(b) shows how the test engine's brake torque varies with hydrogen energy content (0%, 25%, and 50%) and engine speed. We kept the extra air ratio value in Figure 7(c). When hydrogen (H_2) is fed to the intake manifold, the engine causes less damage to the air. The observation of volumetric efficiency of the test engine is lower in the (25% and 50%) hydrogen injection experiments across the full engine speed range, as illustrated in Figure 6(d). A diesel engine has more heating values than H_2(Hydrogen), which has a higher HV than diesel fuel, but due to the engine's lower volumetric efficiency, less torque and power were produced. When 25% energy equivalent hydrogen injection is used, the measured engine power loss varies from 8.1% to 15.1% across the speed range. When 50% energy equivalent hydrogen was introduced, the test engine's power output declined even further, dropping 10.8% to 25.4% below that of a clean diesel engine. When 25% hydrogen is injected, the braking engine power value decreases by 8.1% to 15.1% (on an energy basis), and when 50% hydrogen is introduced, the braking engine power value decreases by 10.8%-25.4% compared to diesel fuel alone.

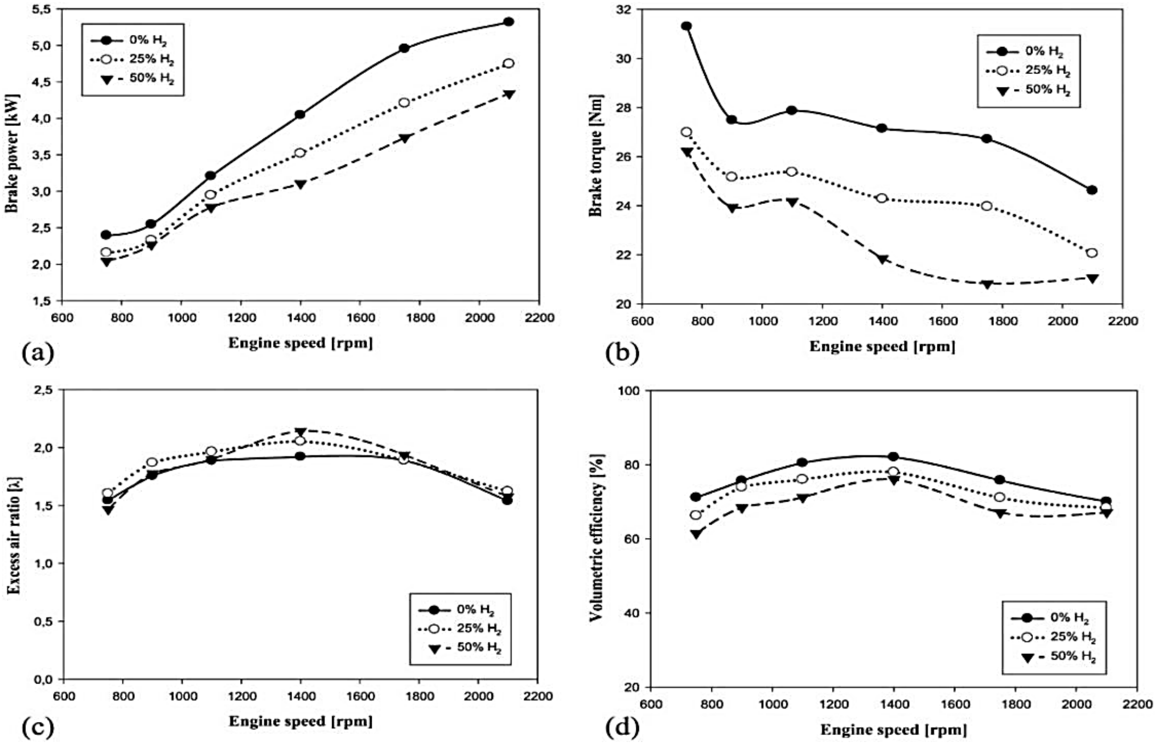

Fig. 7. Deviation of different parameters

In Figure. 8(a) depicts how the BTE value varies with engine speed and hydrogen quantity, whereas Figure 8(b) depicts how the BSFC value varies with engine speed and hydrogen quantity. H_2 Speed of flame is nine times higher than that of diesel fuel. The brake thermal efficiency rating falls by (3.3%-8.1%) with a (25%) hydrogen addition (the overall fuel's energy content) and by 8.2%-15.5% with a 50% hydrogen addition as compared to diesel fuel alone. When the quantity of diesel fuel spent is multiplied by the B.S.F.C and the equivalent diesel fuel quantity calculated from the LSV of hydrogen, the results are shown. When hydrogen accounts for 25% of the fuel's energy content, the BSFC value rises by 3.4%-8.7%; when hydrogen accounts for 50% of the fuel, the BSFC value rises by 9.0-18.4%. Hydrogen often increases the combustion efficiency of diesel fuel. Varde and Frame found that adding hydrogen affects the combustion phase progress, which reduces thermal efficiency. Previous authors' examination of a diesel engine found a decrease in thermal efficiency at low speeds. It is assumed to be the result of an empirically documented reduction in hydrogen combustion efficiency. Hydrogen has a higher molar thermal capacity than N_2, which mixes the gas in the cylinder and decreases the efficiency during combustion.

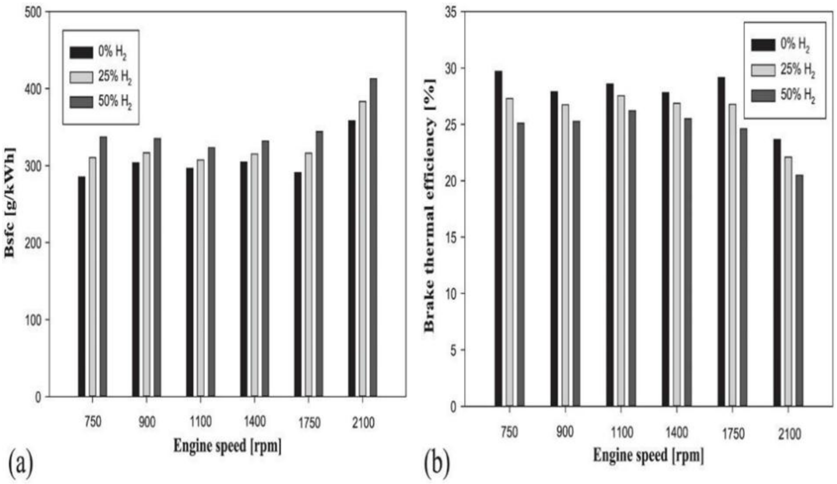

Fig. 8. (a) Brake-specific fuel consumption (BSFC) vs. Engine speed, (b) brake thermal efficiency (BTE) value vs. engine speed

Figure 9(a) depicts the variation in CO emission levels with engine speed at different hydrogen concentrations. When 25% or 50% hydrogen is added to diesel fuel, CO emissions are dramatically decreased at all engine speeds compared to utilizing simply diesel. Associated with only diesel fuel situations (0% hydrogen), a development of (20.4%-65.3%) and (48.5%-66.3%) is found, respectively, with hydrogen addition comparable to 25% and 50% of total fuel as energy content. Figure 9(b) illustrates how CO_2 emission levels fluctuate with engine speed and hydrogen content. Adding hydrogen to diesel fuel reduces CO_2 emissions significantly at engine speeds. Adding 25% hydrogen reduces CO_2 emissions by 12.7%-25.4%, while adding 50% hydrogen reduces CO_2 emissions by 23.4%-38.7% compared to using diesel alone. Hydrogen emits less CO_2 due to its carbon-free nature. When hydrogen is introduced, combustion efficiency improves and combustion time decreases as the hydrocarbon rate of the fuel increases.

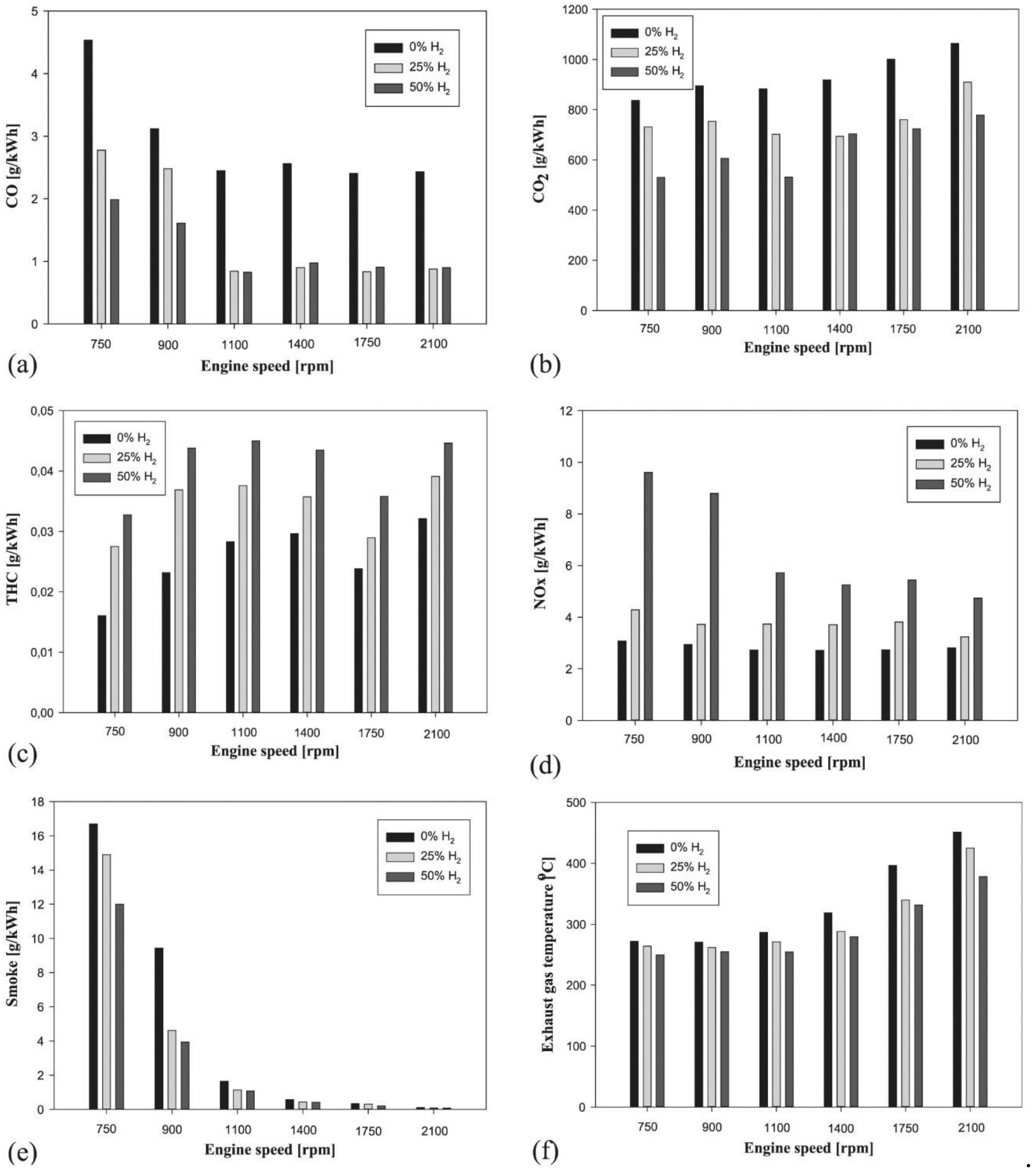

Fig. 9 Disparity of CO, CO_2, THC, NOx,

In associated to diesel fuel (0% Hyd.), the power value of the brake engine lowers by (8.1% to 15.1%) with a (25% hydrogen) addition (as an energy basis) and by (10.8% to 25.4%) with a (50% hydrogen) addition. Furthermore, performance and volumetric efficiency ratings for brake engines have declined as compared to diesel fuel alone (0% hydrogen). Hydrogen can be supplied into the cylinder in place of some air, as long as the surplus air ratio is kept as close as possible. When 25% hydrogen is added (as the energy content of the entire fuel), the brake thermal efficiency value decreases by(3.3% to 8.1%), and when 50% hydrogen is added, it decreases by 8.2%-15.5% when compared to diesel fuel. The inclusion of hydrogen raises the BSFC value throughout all cycles. Similarly, at all engine speeds, hydrogen enrichment during filling results in a significant reduction in CO emissions. With 25% and 50% hydrogen added as the energy content of the whole fuel, there is a (20.4%-65.3%) and (48.5%-66.3%) improvement compared to merely diesel fuel (0% hydrogen). Furthermore, adding hydrogen reduces CO2 levels at all engine speeds.

5. Conclusion

Using H_2 as an inferior fuel in dual-fuel diesel engines has shown considerable potential for improving engine efficiency and reducing harmful emissions. Research indicates that a 30% hydrogen blend offers the best balance, improving brake thermal efficiency to around 27.9% without causing engine knocking, an issue that tends to arise at higher hydrogen concentrations like 90%. Upon hydrogen supplementation, the engine’s specific energy consumption decays, and notable drops in emissions are observed, with NOx levels falling from 1806 to 888 ppm and smoke emissions decreasing from 6.8 to 2.3 BSN. These developments are largely due to hydrogen’s fast-burning nature and cleaner combustion. However, despite these benefits, there are still practical challenges to overcome, such as managing knock at higher hydrogen ratios, refining injection strategies, handling performance during changing engine loads, and confirming safe and efficient hydrogen storage. The current study investigated how metal oxide nanoparticles enhance the efficiency of hydrogen-diesel fuel burning and reduce harmful effects. The research investigated the issues is indispensable for the successful integration of hydrogen into commercial dual-fuel diesel systems.

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