Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

A Review on RCCI Engine Performance Using Hydrogen and Alcohol as Alternative Fuels: Challenges, Opportunities, and Future Prospects

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Abstract:

This review paper captures a detailed overview of an experimental study of a diesel engine performance characteristics in a combination with the Reactivity Controlled Compression Ignition (RCCI) technology when employing different fuel blends. It examines the scientific principles behind the RCCI combustion and the suitability of the technique for improving the efficiency of an engine while eliminating harmful emissions in the presence of high-reactivity and low-reactivity fuels. Particular attention is given to the application of hydrogen and alcohol-fueled fuels in the RCCI diesel engines, testing their effect on the major performance parameters like the brake thermal efficiency, combustion mode, and exhaust emissions.

The review explores the experimental setup, e.g., fuel injection strategies, fuel premixing proportions, and engine modes of operation, to provide a detailed overview of how these parameters affect combustion behaviour and dynamics. The results show that hydrogen and alcohol utilization in RCCI engines significantly improves fuel-air mixing, leading to improved combustion efficiency and reduction of NOx and particulate emissions. The study, however, also refers to some limitations, e.g., the potential for knocking, combustion stability, and need for precise fuel injection timing control and premixing strategies.

The paper also outlines possible future advancements to improve RCCI technology with more advanced control systems, new fuel blends, and improved-engineered engine designs. The limitation and challenge with the use of hydrogen and alcohol in RCCI diesel engines is elaborated, along with recommendations on research directions in the future. From the findings, it is evident that RCCI combustion using such alternative fuels holds tremendous potential towards powering cleaner and more efficient internal combustion engines, aiding global efforts in emission reduction and enhancing sustainability in the transport industry. This paper provides tremendous insight for researchers and industry professionals dedicated to advancing alternative fuel use with modern engine technology.

Introduction:

The transportation industry is a major source of greenhouse gas emissions and air pollution. This has created a pressing need for the creation of cleaner and more efficient engine technologies. One of the technologies that have gained attention in recent years is Reactivity Controlled Compression Ignition (RCCI) diesel engines. RCCI engines are highly efficient and have low emissions [1], which makes them a viable solution for minimizing the environmental footprint of transportation.

RCCI engines merge the advantages of traditional diesel engines and gasoline engines by employing a combination of low reactivity fuel like gasoline or alcohol and high reactivity fuel like diesel or biodiesel to regulate the combustion process [23]. Hydrogen and alcohol have been recognized as potential alternative fuels for RCCI engines because they possess low carbon content and high octane rating[2] [1]. Consequently, there has been increased interest in exploring the performance characteristics of RCCI diesel engines with these fuels. This review paper aims to present an overview of the experimental studies carried out to analyze the performance of an automotive RCCI diesel engine with hydrogen and alcohol as fuels. The paper presents a comprehensive overview of RCCI technology and the application of hydrogen and alcohol [1], [2] as substitute fuels. It also examines the test configuration employed for analyzing the performance of the RCCI diesel engine and discusses results from several tests run to determine engine performance in terms of brake thermal efficiency, emissions, and combustion behavior. Moreover, the paper emphasizes the difficulties and possibilities of the implementation of hydrogen and alcohol in RCCI diesel engines. It makes suggestions for future research in this area, which can assist industry experts and researchers in designing cleaner and more efficient engines. In conclusion, this review paper offers great information regarding the performance features of an automotive RCCI diesel engine employing hydrogen and alcohol as substitute fuels

Gharehghani et al., 2015,focused on the effect of dual fuel combustion in a single cylinder compression ignition engine. The study explores the use of Pongamiapinnata biodiesel (B100) and compressed natural gas (CNG) as main fuels, which were injected during the suction stroke using an electronic controlled unit. The main approaches discussed are the use of CNG as the primary fuel and 18% HCNG, which is regulated by adjusting injector pulse width using a gas management system, and the injection timing kept constant at 43 CA ATDC. Low Temperature Combustion strategies, such as HCCI and LTPCI, were used.

All testing were done at 1500 rpm with a 5 kW electrical power output. The results showed that the use of dual fuel led to a higher in-cylinder pressure with a shorter heat release rate duration than conventional methods. It also resulted in more stable combustion and reduced cycle-to-cycle variations at higher engine loads. This approach reduced harmful exhaust gases from CNG dual-fuelled engines while maintaining engine performance levels at acceptable limits. The brake thermal efficiency improved significantly, up to 64% with HCNG share.

While NOx emissions increased marginally, they remained less than the base biodiesel fuel. Smoke emissions were also lower than the base biodiesel fuel, which reduced unburned hydrocarbon and carbon monoxide emissions and lowered combustion losses.

In conclusion, this research provides an alternative solution to reducing harmful exhaust gases from CNG dual-fuelled engines while maintaining engine performance levels at acceptable limits.

Shukla, P.Cet al., 2021, examines the impact of dual fuel and blend ethanol fuelling alternatives on compression ignition engine thermodynamic efficiency and emissions. Ethanol can decrease global emissions without sacrificing standards, the research indicates. Transport will still be emitting CO2 as a result of population growth. The replacement of fossil fuels can help reduce greenhouse gas emissions and pollutants.

The research found that there were some advantages from high ethanol, rail pressure, and EGR dual-fuel combustionThese benefits include minimizing emissions and noise while maximizing efficiency. The use of ethanol as a fuel reduces emissions and noise levels while increasing the overall efficiency of the engine.

In conclusion, the study provides evidence that ethanol could be an effective alternative for reducing global emissions while meeting current standards. The results indicate that dual-fuel combustion, using high ethanol, rail pressure, and EGR levels, can improve the thermodynamic performance and reduce emissions and noise levels while maximizing efficiency.

S. Rajkumaret al., 2021, provides practical solutions to reduce emissions from conventional fossil fuel sources by utilizing alternative fuels such as alcohol and biodiesel in compression ignition (CI) engines. The advantages of these fuels over traditional diesel include higher latent heat of evaporation, which is beneficial for NOx reduction, fuel-bound oxygen that reduces smoke emission, and their renewable nature.

However, the paper also highlights that the direct use of alcohols may not be suitable for CI engines due to their lower cetane and viscosity characteristics. Therefore, the preferred approach is the dual-fuel mode or blending with diesel.

In addition, the paper provides guidance to policymakers on how to reduce harmful emissions while meeting power demands through efficient engine technologies. This includes considering the benefits of higher latent heat of evaporation, fuel-bound oxygen, and the renewable nature of these alternative fuels. This paper offers a viable solution to the problem of reducing emissions from conventional fossil fuels and promotes the use of alternative fuels in CI engines.

Dempsey et al., 2014,comprehensively reviews and compares various low temperature combustion strategies and their performance without exhaust gas recirculation (EGR). It gauges engine performance, emissions, combustion sensitivity to intake conditions, and fuel injection strategy's capacity to manage sensitivities.

The results indicate that all three methods investigated - HCCI, RCCI, and PPC - exhibited high gross indicated efficiency (47%) and ultra-low NOx and soot emissions at the baseline operating condition. Additionally, these methods displayed similar sensitivities to intake conditions that could be corrected through global fuel reactivity, with no negative implications on NOx emissions for both HCCI and RCCI. However, PPC faced difficulty in correcting for observed sensitivity in some cases, resulting in a decrease of NOx emission levels.

The comprehensive analysis and comparison of low temperature combustion techniques' engine performance, emissions, sensitivity to intake condition, and the capability to control sensitivities give this research prominence.It confirms the existing knowledge about these types of advanced compression ignition combustion strategies having challenges in controlling their combustion phasing but also demonstrates how they can be controlled on a cycle-to-cycle basis through fuel injection strategy. Additionally, the paper reinforces good engine performance with clean exhaust emission levels.

Sage L. Kokjohn et al., 2009,Fuel reactivity changes can influence the way in which premixed charge compression ignition (PCCI and HCCI) combustion methods operate. The research employed a KIVA-CHEMKIN code with a reduced main fuel method for enhanced fuel mixtures and EGR alternatives for HCCI application at 6 bar net IMEP and 11 bar net IMEP. Engine testing with the dual-fuel PCCI strategy revealed that improved fuels may enable more extensive PCCI operation. This extension meets heavy-duty emissions regulations and achieves 50% thermal efficiency.

The study found that neither neat diesel nor gasoline alone could achieve minimum fuel consumption. Instead, decreasing amounts of both fuels were needed as the load increased. At 11 bar, an 80% PRF/50% EGR combination resulted in the best. Dual-fuel

PCCI, where port-injected gasoline was fixed with many early injections of diesel fuel usinga regular injector, achieved the desired output in the second half of testing. The study found that an optimal blend of gasoline and diesel fuels, along with EGR rates, can be used to achieve high efficiency, confirming previous research on PCCI/HCCI operation using neat gasolines or diesels alone. It also provided new insights into the potential for dual-fuel operations in these engines.

The paper also discusses the advantages of using a low-pressure, narrow-angle GDI-type injector over a conventional, high-pressure, wide-angle diesel injector. Firstly, the use of the former reduces liquid impingement on the cylinder liner when used for very early injection timings near BDC. Secondly, it helps to extend gasoline consumption until after the transition to thermal ignition.

Sunmeet Singh Kalsi,et al., 2017, provides a comprehensive Combustion, performance, and exhaust emissions of hydrogen-blended compressed natural gas were investigated. They employed a 1500-rpm, 5-kW electrical power output engine.Pongamiapinnata biodiesel was used as a pilot fuel, while CNG and 18% HCNG were injected during the suction stroke. Brake thermal efficiency was improved by 64% compared to baseline CNG, and CO and HC emissions were decreased. Smoke emission was lower than just using B100 alone, but NOx increased marginally, yet still remained less than when only B100 is used.

This paper adds to the existing literature by providing insight into how HCNG can improve brake thermal efficiency while reducing CO, HC, and smoke emissions compared to base CNG without significantly increasing NOx emission levels. This is in contrast with other studies that have found that adding hydrogen as a gaseous fuel charge under dual-fuel mode leads to an increase in NOx emissions. The findings of this study suggest that blending hydrogen into compressed natural gas could be an effective way of improving performance characteristics and reducing harmful emissions.

In conclusion, this study confirms that blending hydrogen into compressed natural gas could be an effective way of achieving these goals without having the same negative impacts on NOx levels as other approaches have had in the past.

Kakoee, et al., 2019 comprehensive paper analyzes the impact of different fuels and additives on Reactivity Controlled Compression Ignition (RCCI) engines. The study utilizes both numerical modeling and experimental data to investigate how hydrogen addition affects combustion characteristics when used with natural gas/dimethyl-ether or natural-gas/diesel fuel mixtures. This investigation is novel and has not been done before.

The study examines the differences between diesel and dimethyl ether as high reactivity fuels, including their impact on indicated mean effective pressure (IMEP), start of injection (SOI) timing, burn duration (BD), and temperature levels. Additionally, the study analyzes carbon monoxide emission from both types of fuel mixture containing either Natural Gas & Dimethyl Ether or Natural Gas & Diesel, along with unburned hydrocarbons emissions for each case study scenario tested.

The results of the study indicate differences between diesel and dimethyl ether as high reactivity fuels. The addition of hydrogen had a greater impact on the start of combustion when used with NG/DME than it did for NG/Diesel mode. Additionally, temperature levels were higher when diesel rather than DME was employed, which caused an increase in nitrogen oxide emissions.

Overall, this study concludes that the addition of hydrogen can effectively improve RCCI engine performance by decreasing CO and UHC emissions, controlling SOC and CA50 across both types of fuel mixture studied here containing either Natural Gas & Dimethyl Ether or Natural Gas & Diesel. This work is both novel and confirmatory at the same time.

AyatGharehghan,et al., 2019, comprehensive review paper examines the performance and emissions characteristics of three different fuels, namely natural gas, ethanol, and methanol, when used in Low Temperature Combustion (LTC) engines. It also provides valuable information on optimizing fuel selection based on engine load and air-fuel ratio, which can be useful for flex fuel vehicles (FFVs).

Five test data sets of a heavy-duty RCCI engine were employed. The model employed in the research can predict start of combustion, crank angle degree at 50% burn (CA50), and burn duration under steady and transient conditions. The maximum mean pressure and its position were also predicted by the model. The maximum mean errors for these estimates range from 1.7 CAD to 2.3 CAD, respectively, for SOC and CA50, and less than 0.5 bar for IMEP under steady state conditions, and 0.8 bar for IMEP under transient conditions. The model predicts output power more precisely without any significant effect due to Exhaust Gas Recirculation (EGR) output power prediction.

The study collected data on the performance of each fuel under various operating conditions such as intake temperature, air-fuel ratio (equivalence ratios), indicated mean effective pressure (IMEP), and start of combustion (SOC).

The study concludes that natural gas is the optimal fuel for Homogeneous Charge Compression Ignition (HCCI) strategy at higher intake temperatures and rich mixture conditions (high loads). Meanwhile, ethanol and methanol are good choices for lower intake temperatures and lean mixtures (light loads). Natural gas is a suitable choice for mixtures with an equivalence ratio greater than 0.3 ($\varphi > 0.3$) and intake temperature higher than 430 K (T ivc> 430 K), whereas ethanol performs well for $0.2 < \varphi < 0.3$.

Jing Li et al., 2017,focuses on managing RCCI engines through fuel adoption and controllable engine parameters. Alternative fuel combinations, RCCI engines run on diesel/gasoline and NG/diesel, which provides improved thermal efficiency and ultra-low NOx and PM emissions over CDC. Optimization of the combustion process for better performance can be achieved by adjusting fuel ratios, injection timings, split injection fractions, EGR rates, CRs, and piston bowl shapes. Additives can also improve the cetane number, increasing the reactivity gradient inside the cylinder and controlling the pressure rise rate during the combustion phase.

Reactivity-controlled combustion is achieved by stratifying the cylinder with two fuels having different cetane numbers and strategically adjusting to provide the optimal performance. RCCI engine combustion is also dependent on structural parameters like CRs and piston bowl shape.

Yifeng Wang et al., 2016,comprehensively reviews the effect of operational parameters on RCCI combustion and emissions, identifying optimal control strategies for efficient operation across different loads. Optimization of these parameters can result in improved fuel efficiency and reduced pollutant emissions compared to traditional SI or CI engines. The research can be applied in designing engines with enhanced capabilities while still maintaining low NOx and soot emissions at moderate-to-high engine loads operating in diesel/gasoline RCCI combustion regimes.

The findings of this paper support existing literature and current knowledge, which suggest that RCCI combustion is a promising technology. The detailed analysis on how different operational parameters can be optimized to achieve better performance characteristics provides further evidence to support the use of RCCI as an alternative engine technology compared to SI or CI engines.

This paper focuses on the effects of adding hydrogen as an additive to CNG/Diesel RCCI engines. A Ricardo E6/MS single cylinder engine with a representative Comet MK.V pre-chamber system confirms CFD modeling and Chemkin solver numerical predictions. Three concentrations of hydrogen (10%, 20%, and 30%) were studied, and CFD simulations modeled parameters such as ignition delay, heat release rate diagrams, IMEP, gross work output, and IFCE.

Adding hydrogen to the natural gas-air mixture increases the temperature inside the cylinder, reducing UHCs by 29.8% and CO by 35.5%. However, nitrogen oxide emissions increase due to the temperature rise within the cylinder, with approximately a 23% increase at 30% concentration level according to numerical simulations. The optimal amount proposed is between 10-15%, where there is a 20% and 15% decrease, respectively, for CO and UHC, but a 14% increment observed for NOx rate.

RCCI strategy research indicates that higher hydrogen concentrations enhance combustion and engine performance. Two fuels, a high-reactivity. The use of two fuels, one high-reactivity fuel for auto-ignition and a low-reactivity fuel fed through intake valves, can lead to improved efficiency compared to conventional diesel engines without sacrificing too much power output or causing excessive noise due to higher peak pressures associated with PCCI and HCCI strategies.

YabinDong,et al., 2016,provides a comprehensive review of the potential of methanol as an alternative fuel and RCCI technology in reducing CO2, NOx, and PM emissions. The paper also examines the influence of diesel injection strategies on combustion characteristics. The experiments were conducted by varying parameters such as methanol substitution rate (MSR), air mass flow, and air intake temperature to observe different results from the experiment.

The results of the experiment confirmed that methanol has the potential to reduce CO2, NOx, and PM emissions due to its lower C/H ratio, local oxygen content, and high evaporation latent heat. RCCI technology was found to be an advanced engine technology for reducing NOx emissions. Additionally, the results showed that single diesel injections significantly reduced NOx emissions. The air intake temperature also played a role when it came to fuels used during experiments, while each particular MSR was found to have its own precise operation window for better efficiency.

Furthermore, this paper provides novel insights into how diesel injection strategies influence combustion characteristics, with single diesel injections being found to reduce NOx emissions significantly.

Rolf D. Reitz, et al., 2016, provides an overview of Combustion and fuel research have improved the fuel economy of diesel or CI engines. It is aimed at "reactivity controlled compression ignition" (RCCI), a type of homogeneous charge compression ignition, for dual fuel engine combustion. It is comparing light-duty vehicle testing with conventional diesel fuel and other alternative fuels such as natural gas, ethanol, and biodiesel with RCCI/HCCI technology to conventional CI engine technology.

The study contributes to the existing literature by providing evidence of the potential for advanced combustion technologies such as RCCI and HCCI to enhance fuel efficiency while meeting emissions regulations. The findings suggest that these new technologies can deliver better performance outcomes in terms of lower pollutant emission levels and increased fuel efficiency compared to conventional diesel engines, making them a viable option for reducing environmental impact and saving money on fuel costs. This research is innovative in its approach as it combines experimental data from real-world tests with computational models to analyze the effects of different types of fuels when used in combination with advanced combustion techniques like RCCI or HCCI.

MojtabaEbrahimi ,et al., 2019,investigates the effects of adding hydrogen to landfill gas and diesel oil in a single cylinder heavy-duty diesel engine set at 9.4 bar IMEP. The experiment demonstrated that adding hydrogen resulted in a reduction in fuel consumption per cycle, an increase in peak pressure, a decrease in engine load up to 4%, an improvement in methane dissociation rate, a shortening of combustion duration, and the prevention of diesel knock. Additionally, emissions from engines were significantly decreased. The energy content of the fuel was kept constant while diesel fuel and hydrogen were added to landfill gas.

The significance of this paper lies in the valuable insights it provides into the potential benefits of adding hydrogen to landfill gas and diesel oil, including increased efficiency and reduced emissions from engines using these fuels. The novelty of this research stems from the fact that no other study has been published on the use of LFG with hydrogen addition for RCCI combustion before now, making this paper the first in its field. The findings confirm that adding hydrogen to landfill gas and diesel oil can lead to a reduction in fuel consumption per cycle, an increase in peak pressure, a decrease in engine load up to 4%, an improvement in methane dissociation rate, a shortening of combustion duration, and the prevention of diesel knock. Moreover, emissions from engines were significantly lower than those from other fuels, such as gasoline or ethanol, that have been used for similar applications in the past.

JeongwooLee et al., 2017 examines the impact of hot and cooled exhaust gas recirculation (EGR) and premixed mass percentage on Methanol/Diesel dual fuel reactivity controlled compression ignition (RCCI) combustion in a modified 3-cylinder light-duty, turbocharged, CRDI diesel engine. The research findings indicate that cooled EGR at a rate of 26% results in improved combustion characteristics, including less cycle-to-cycle variation, lower NOx and smoke emissions, and increased thermal efficiency when using 76%-81% methanol for both load conditions. Furthermore, higher load conditions demonstrate less cyclic variations compared to lower loads due to their increased pressure rise rate, which further enhances emission reduction.

Prior studies have demonstrated that EGR is a critical parameter in controlling ringing intensity and NOx emissions in RCCI operation, while only a few researchers have studied the cyclic variation of dual-fuel RCCI operation. This study confirms that introducing cooled EGR above 40% results in less cycle-to-cycle variations and better NOx emission reduction compared to hot EGR operations when using 76%-81% methanol for both load conditions. The findings also demonstrate that higher loads exhibit lower cyclic variations due to their increased pressure rise rate, which contributes to further emission reduction.

Another study examined the potential for high thermal efficiency at low loads and suppressing maximum in-cylinder pressure rise rate (PRRmax) at higher loads using two different operating strategies of gasoline and diesel dual-fuel premixed compression ignition (PCI) in a single-cylinder compression ignition engine. The results indicate that mode A provided better gross indicated thermal efficiency than mode B, but mode B enabled lower PRRmax values due to splitting heat release rate peaks, which facilitated smoother combustion without compromising emissions or safety parameters like PRR max limit set forth by regulatory bodies.

Diesel engines have high durability but also high emissions due to their heterogeneous mixture condition, while gasoline engines can reduce NOx emissions by using a three-way catalyst through stoichiometric combustion. However, diesel engines require lean burn conditions for efficient operation, making it impossible to use a three-way catalyst.

Ganesh Duraisamy, et al., 2019,investigates the impact of hot/cooled exhaust gas recirculation (EGR) and premixed mass percentage on Methanol/Diesel dual fuel reactivity controlled compression ignition (RCCI) combustion using a modified 3-cylinder, light duty, turbocharged, CRDI diesel engine with port fuel injection of methanol and EGR. The experiments were conducted at two different loads - 3.4 bar BMEP and 5.1 bar BMEP - by varying EGR and premixed mass percentage with sulfur-free diesel as direct injection fuel and 99% pure methanol as port injection fuel. The results revealed that cooled EGR of 26% led to less cycle-to-cycle variation, better reduction in NOx emissions, smoke emission, and improved thermal efficiency compared to hot EGR operation for both load conditions when using 76%-81% methanol, respectively. Additionally, introducing cooled EGR above 40% resulted in less cycle-to-cycle variations with better reduction in NOx emissions. At higher load condition, it exhibited lesser cyclic variations than the lower one due to its increased pressure rise rate, which helps to further reduce emissions. This work is significant because it provides a comprehensive understanding of the influence of hot/cooled EGR and premixed mass percentage on Methanol/Diesel dual fuel RCCI combustion. It verifies previous research that EGR has a significant function in maintaining proper ringing intensity and NOx emissions in RCCI operation. Cyclic fluctuation of dual fuel RCCI operation has been rarely studied.

Jamrozik et al., 2019, presents experimental research on a dual-fuel engine that operates on diesel fuel injected directly into the cylinder and CNG gas (compressed natural gas) injected into the intake manifold. The energy share of CNG co-fired with diesel fuel ranged from 0% to 95%. Increasing the energy share of CNG co-combusted with diesel in the CI engine increases ignition delay, intensifies combustion process leading to an increase in maximum pressure in cylinder and rate of heat release as well as pressure rise rate, and shortens overall duration of combustion. Stable operation was observed when using 30%-45% shares for compressed natural gas compared to conventional engines running only on Diesel Fuel Supply. Co-combustion reduces Nitric Oxide emissions while increasing Hydrocarbon Emissions beyond 45%. In addition, Carbon Dioxide emission is reduced significantly, along with almost complete elimination of Carbon Monoxide exhaust gases.

F. Legrottaglie et al., 2019,presents the preliminary results of an experimental study conducted on a modified light-duty diesel engine operating in Reactivity Controlled Compression Ignition (RCCI) combustion mode. The study focused on two operating points, 150 Nm and 300 Nm at 1500 rpm, to identify an upper threshold beyond which diesel injection is no longer sufficient for obtaining regular RCCI combustion.

Gasoline was found to be preferable to diesel as it increases ignition delay, promoting fuel-air mixing and reducing the need for EGR. However, at low loads, spark assistance may be required to control worsening ignition timing. The research conducted in this paper showed an improvement in brake thermal efficiency when substituting a majority portion of diesel fuel with gasoline. However, medium load operation posed a risk of knocking due to the presence of a large amount of unburnt hydrocarbons, as expected from previous studies on the RCCI technique.

The findings also demonstrate the importance of EGR for controlling ignition timing and Rate of Heat Release (RoHR), while improving brake thermal efficiency without significantly increasing peak pressure or noise levels.

Kumbhar et al., [2021],provides a comprehensive review of the potential of Reactivity Controlled Compression Ignition (RCCI) strategy in achieving BSVI emission standards. It assesses the cost and performance of existing engines equipped with advanced after-treatment technologies, as well as examining various experiments conducted with dual-fuel PCCI and HCCI operations. The findings suggest that RCCI has great potential for reducing NOx and PM emissions, while also improving thermal efficiency without the need for a complex or costly exhaust treatment system.Additionally, the paper highlights the significance of fuel stratification in controlling combustion characteristics and explores various experiments conducted with dual-fuel PCCI and HCCI operations. The research reveals that current work is limited in the context of hybrid vehicles, but suggests that modifications, such as advancements in engine control systems or mode swing technologies, could be beneficial.

The novelty of this work lies in its assessment of existing engines equipped with advanced after-treatment technologies from both cost and performance perspectives, which provides valuable insights for researchers and industry professionals alike.

Szamrej et al., [2021], presents a review of the experimental investigations conducted to evaluate the potential benefits of using hydrogen and alcohol as alternative fuels in an automotive Reactivity Controlled Compression Ignition (RCCI) diesel engine. The review examines the engine performance characteristics, including brake thermal efficiency, emissions, and combustion characteristics, of using hydrogen and alcohol as alternative fuels in RCCI diesel engines.

LuoJianbin, et al., 2022, reviewed research paper investigates the application of hydrogen as a low reactive fuel to optimize the transition regimes between partially premixed and reactivity-controlled combustion in an existing diesel engine. The study employs injection phasing, reactivity phasing, and hydrogen enrichment strategies to enhance the stability of the interposed combustion zone, aiming to improve performance, emissions, and stability characteristics. The research reveals that higher rates of hydrogen induction lead to improved combustion stability, resulting in notable reductions in soot, total unburnt hydrocarbon (TUHC), and nitrogen oxide (NOx) emissions compared to a control trial. Employing Response Surface Methodology (RSM), the paper identifies optimal conditions for the interposed zone with increased exergy efficiency and desirability. The study underscores the feasibility of achieving advanced low-temperature combustion concepts without significant design modifications, showcasing the practical potential to enhance existing diesel engine performance and reduce environmental impact.

Acar, et al., 2020, reviewed paper explores the viability of hydrogen as a sustainable transportation fuel, with a focus on its application in internal combustion engines. It underscores hydrogen's advantages such as energy density, availability, and ease of transportation, while emphasizing the importance of producing hydrogen with minimal emissions from renewable sources for true sustainability. The study compares various vehicle types, considering emissions, energy efficiency, fuel consumption, price, and range. Fuel cell vehicles emerge with the highest performance ranking, followed by hydrogen-fueled internal combustion engines and biofuel vehicles. Conventional vehicles perform poorest, trailed by electric and hybrid ones. The paper's practical implications encompass the potential for hydrogen to revolutionize transportation, replacing fossil fuels for greater efficiency and lower emissions. The study's findings could guide investments in hydrogen technology and infrastructure to foster a greener transportation sector.

Karczewski M et al., 2020, reviewed paper titled "A Review of Low-CO2 Emission Fuels for a Dual-Fuel RCCI Engine" delves into the potential benefits of employing low-CO2 emission fuels in reactivity controlled dual fuel engines (RCCI) to mitigate exhaust gas emissions. The study suggests that incorporating fuels with hydrogen additives or undergoing hydrotreatment could lead to significant reductions in emissions, offering a feasible route to meet stringent emissions regulations. The review underscores the effectiveness of such fuels in RCCI engines, highlighting their compatibility and potential for high thermal efficiency. Additionally, the paper explores the utilization of biocomponent-based oils as diesel fuel additives and the applicability of hydrotreated vegetable oil (HVO) in dual-fuel systems. The research underscores the importance of optimizing combustion chamber design in RCCI engines to enhance fuel combustion and mitigate harmful exhaust compounds. The

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methods employed involve comprehensive compilation and analysis of existing research, encompassing scientific publications, conference materials, multimedia presentations, and various information sources. The study provides valuable insights into the feasibility and benefits of utilizing low-emission fuels in dual-fuel engines, drawing conclusions based on a broad range of knowledge sources.

Rahimi et al., 2020,The study is concerned with the way Reactivity Controlled Compression Ignition (RCCI) combustion with natural gas and diesel oil can enhance the use of hydrogen energy in heavy-duty diesel engines. Research covers two ways strategies: introducing hydrogen or syngas mixed with exhaust gas recirculation to natural gas. Simulation results indicate that hydrogen addition can increase the hydrogen energy share by up to 40.43% with a negligible 1% engine power reduction, while syngas addition boosts the hydrogen energy share by up to 27.05% and enhances engine power output by over 4%. Both of the approaches minimize per-cycle hydrocarbon fuel consumption by 46.60% and 33.86%, respectively. 50% gross indicated efficiency and significant emission reductions over RCCI combustion with exclusive consumption of natural gas and diesel oil were realized through the research. The research highlights the potential for improved efficiency and emission reduction in heavy-duty diesel engines by incorporating hydrogen or syngas into RCCI combustion.

Haliset al.,2023, Experiments showed that using a premixed ratio of PR25 at 50 °C resulted in the lowest NOx, HC, and CO emissions with the best fuel efficiency, as indicated by a BSFC of 268 g/kWh. This highlights the importance of achieving the optimal premixed ratio to enhance RCCI engine performance. Experimental outcomes showed that PR25 at 50 °C resulted in the widest operating range, and PR50 at 70 °C resulted in the widest range. The NOx emissions were minimum at 30 °C, with a compromise between emissions and operation range. The findings indicate the need for regulation of intake air temperature during RCCI operation.

Thippeshnaik, G.,et al., 2023, the research concluded that the incorporation of higher alcohols such as 1-heptanol and n-octanol in hybrid biodiesel-diesel blends enhanced engine performance and combustion. Ternary blends (B20H10, B20H20, B20O10, B20O20) exhibited improved brake-specific fuel consumption and brake thermal efficiency compared to the binary blend (B20) and diesel at full load. Although these blends lowered carbon monoxide and unburned hydrocarbons, they increased carbon dioxide and nitrous oxide emissions. The results indicate that ternary blends are a cleaner option compared to diesel, but more research is required to overcome their environmental problem and optimize fuel composition.

Sengupta, A.,et al.,2023, The research confirmed that the use of n-butanol with split injection phasing significantly affected improving engine performance by lowering brake-specific energy consumption by 28.86% and exergy efficiency by 110.29% in comparison to biodiesel. The emission analysis confirmed that there were tremendous reductions in NOx (58.56%), soot (82.48%), CO (83.48%), and unburnt hydrocarbons (97%) under full load, which confirms that cleaner combustion is achievable. These results confirm that the addition of butanol to RCCI engines improves the fuel efficiency and reduces emissions, and therefore is a promising alternative fuel. Injection strategy should be optimized and engine performance evaluated for the long term.

Krishnasamy, A., et al., 2023,the research investigated the port-injected RCCI (PI-RCCI) technique, where fuels of various reactivity are mixed to encourage engine efficiency and minimize e missions. The PI-RCCI strategy reduced low-load CO and HC emissions by 70% and 48%, respectively, compared to traditional RCCI. Performance tests on a modified single-cylinder diesel engine with waste cooking oil biodiesel and plastic waste oil recorded a 20% improvement in brake thermal efficiency and a 13% decrease in brake-specific fuel consumption. Nitrogen oxide (NOx) emissions also recorded a decrease, while soot concentration remained unchanged. These results indicate that PI-RCCI is a feasible process for cleaner and more efficient combustion processes.

Deresso, H., et al., 2023,the research used a triple-fuel RCCI diesel engine with port-injected G5E15 blend and direct-injected diesel. The research showed that the G5E15-RCCI setup achieved a maximum cylinder pressure of 90.76 bar and heat release rate of 63.02 J/deg at 3000 rpm, which was higher than the baseline

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fuel. The emission tests showed lower NOx and CO2 emissions in the G5E15-RCCI operation but higher CO and unburned hydrocarbons. Nevertheless, the G10E10-RCCI setup showed lower CO and hydrocarbon emissions, which reflect a more favorable environmental effect. These results show the promise of optimized triple-fuel RCCI approaches for better efficiency and reduced emissions.

Ravi, H.,et al., 2023,The study explored an RCCI engine fueled by a blend of n-octanol, moringaoleifera oil, and diesel to optimize injection pressure (500-1000 bar) and timing (23-27° before top dead center) to maximize performance and reduce emissions. According to the Box-Behnken design, the researchers determined optimal parameters for maximizing brake thermal efficiency and brake power with a reduction in hydrocarbon and nitrogen oxide emissions simultaneously. Some piston bowl geometries were also examined using an L27 orthogonal array, indicating their effects on combustion characteristics. The findings validate the potential of improving RCCI engine efficiency through accurate tuning of fuel injection strategies and piston design.

Dwarshala, S. K. R., et al., 2023,The article discusses advancements in Reactivity Controlled Compression Ignition (RCCI) engines, with an emphasis on the influence of significant parameters such as fuel reactivity, premixing ratio, injection strategies, and piston configuration on emissions and performance using alternative fuels. RCCI technology is promising in minimizing nitrogen oxides (NOx) and particulate matter emissions and maximizing fuel efficiency. The review also discusses the influence of computational fluid dynamics (CFD) in optimizing the design of combustionchamber geometry. Nevertheless, additional CFD model refinement is needed to understand RCCI combustion more comprehensively, particularly in the context of using it at elevated engine loads. These findings augment the advancement of RCCI as a more efficient and sustainable combustion strategy.

Agarwal, A. K., et al., 2021,the research tested RCCI combustion with a diesel-butanol blend fuel, which demonstrated port-injected butanol to enhance combustion and engine performance over conventional diesel combustion. The butanol RCCI technique lowered NOx emissions and particulate matter concentration considerably. Higher premixed ratios of butanol further enhanced emissions and combustion performance, although overall performance was invariant. The results also demonstrated variability in combustion behavior with other RCCI fuels such as methanol and ethanol, which placed butanol on the list of low-reactivity fuel candidates. The results indicate that butanol is a viable candidate for cleaner and efficient RCCI engine operation.

Algayyim, S. J. M., et al., 2021,The research tested mixing iso-butanol (isoB) and normal-butanol (nB) with diesel and concluded that a 5% isoB–5% nB–90% diesel blend showed a minor improvement in brake power but higher fuel consumption at high blending levels. Higher isoB content resulted in higher peak cylinder pressure and heat release but lower CO emissions to a large extent. nB blends reduced unburned hydrocarbon emission due to easier oxygenation. Both nB and isoB blends resulted in minor reductions in NOx, and nB provided better performance. The results conclude that mixing the two isomers maximizes combustion and emission performance more than either of them used separately.

Jamrozik, A., et al., 2021,the research indicated that the addition of n-butanol to diesel enhanced combustion, with 39% longer ignition delay and 57% shorter combustion time at 60% blend. The highest thermal efficiency of 41.35% was obtained using a DB40 blend, indicating better performance with the appropriate fuel mixture. Analysis of emissions indicated higher NOx emission with higher n-butanol content, and minimum CO with the DB50 blend. Surprisingly, soot emissions decreased significantly—more than 43 times lower—at 60% blend, indicating the possibility of cleaner and more efficient combustion with n-butanol-diesel blends.

Noroozi, M. J., et al., 2020, the research analyzed the effect of diesel injection pressure and timing on a diesel-butanol RCCI engine through high-fidelity combustion simulations. Out of 36 injection strategies that were tested, the best configuration—1000-bar spray pressure, 45° CA BTDC injection, and 145° spray angle—recorded substantial emission reductions: CO by 26%, NOx by 86%, PM by 71%, and HC by 17.25%. Fuel efficiency was also enhanced, with ISFC reducing by 2.3%, IP by 2.4%, and ITE by almost 2%. The results show the potential of optimal injection strategies to improve RCCI engine efficiency and reduce emissions.

Ganesan, N., et al., 2020,The experiment was conducted on RCCI operation with n-butanol as a low-reactivity fuel and mahua oil as a high-reactivity fuel in a diesel engine. Results indicated considerable emission reduction, with smoke reducing by 45.4% and NO emissions by 33.1% at full load compared to conventional single-fuel operation. Brake thermal efficiency (BTE) increased by 6.2% with a 20% n-butanol energy fraction, although higher fractions resulted in a slight reduction. RCCI operation increased ignition delay at part load but reduced at full power, accompanied by rising cylinder pressure and heat release rate, which indicates improved combustion characteristics.

Singh, A. P., et al., 2021,The study explores the use of mineral diesel and methanol in an RCCI engine to mitigate global warming and strict emission standards in the transport sector. Experimental analysis at various loads and premixed ratios showed promising results in emission and efficiency enhancement. The study demonstrates that RCCI combustion using methanol can reduce toxic emissions by a significant amount while enhancing thermal efficiency, which makes it a viable alternative for cleaner engine technology. The study shows the viability of new combustion methods in meeting environmental standards and fuel efficiency.

Conclusion:

The review emphasizes future advantages associated with the application of hydrogen and alcohol in RCCI diesel engines as being lower emission and better performance of the engine. The test results in these studies indicate improvements in engine efficiency and emission levels, with a performance of the engi ne still ensured, when using hydrogen and alcohol as substitute fuels.
But the review reports that the application of hydrogen and alcohol in RCCI diesel engines remains plagued by challenges, including limitations on storage and infrastructure for fuel. Further research is needed to improve the efficiency of the engine and to find out about any possible complications with the use of alternative fuels. Overall, this review paper offers useful information on the performance of a hydrogen and alcohol-fuelled automotive RCCI diesel engine as a substitute fuel. The results of this review paper can be utilized by researchers and industry professionals in the design of more efficient and cleaner engines, which is vital in the search for the mitigation of greenhouse gas emissions and air pollution from the transport sector.

References :

[1] Ebrahimi, M., &Jazayeri, S. A. (2019, March). Effect of hydrogen addition on RCCI combustion of a heavy duty diesel engine fueled with landfill gas and diesel oil. *International Journal of Hydrogen Energy*, *44*(14), 7607–7615. https://doi.org/10.1016/j.ijhydene.2019.02.010

[2]Gharehghani, A. (2019, March). Load limits of an HCCI engine fueled with natural gas, ethanol, and methanol. *Fuel*, *239*, 1001–1014. https://doi.org/10.1016/j.fuel.2018.11.066

[3]Maciej Mikulski, Sudarshan Ramesh, CemilBekdemir, Reactivity Controlled Compression Ignition for clean and efficient ship propulsion, Energy, Volume 182,2019, Pages 1173-1192, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2019.06.091.

[4]Paykani A, Kakaee A-H, Rahnama P, Reitz RD. Progress and recent trends in reactivity- controlled compression ignition engines. *Int. J. Engine Res.* 2015;**7**:481–524. [Google Scholar]

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[5]AyatallahGharehghani, Reza Hosseini, MostafaMirsalim, S. Ali Jazayeri, TalalYusaf,An experimental study on reactivity controlled compression ignition engine fueled with biodiesel/natural gas,Energy,Volume 89,2015,Pages 558-567,ISSN 0360-5442, https://doi.org/10.1016/j.energy.2015.06.014.

[6] Shukla, P.C., Belgiorno, G., Di Blasio, G., Agarwal, A.K. (2021). Introduction to Alcohol as an Alternative Fuel for Internal Combustion Engines. In: Shukla, P.C., Belgiorno, G., Di Blasio, G., Agarwal, A.K. (eds) Alcohol as an Alternative Fuel for Internal Combustion Engines . Energy, Environment, and Sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-0931-2_1

[7]Rajkumar, Sundararajan&Jeyaseelan, Thangaraja. (2021). The Potential of Various Alcohol Fuels for Low-Temperature Combustion Engines. 10.1007/978-981-16-0931-2_6.

[8] (Gharehghani et al., 2015) Dempsey, A. B., Walker, N. R., Gingrich, E., & Reitz, R. D. (2014, January 21). Comparison of Low Temperature Combustion Strategies for Advanced Compression Ignition Engines with a Focus on Controllability. *Combustion Science and Technology*, *186*(2), 210–241. https://doi.org/10.1080/00102202.2013.858137 (Dempsey et al., 2014)

[9] Kokjohn, S. L., Hanson, R. M., Splitter, D. A., & Reitz, R. D. (2009, November 2). Experiments and Modeling of Dual-Fuel HCCI and PCCI Combustion Using In-Cylinder Fuel Blending. *SAE International Journal of Engines*, *2*(2), 24–39. https://doi.org/10.4271/2009-01-2647

[10]Kalsi, S. S., & Subramanian, K. (2017, February). Experimental investigations of effects of hydrogen blended CNG on performance, combustion and emissions characteristics of a biodiesel fueled reactivity controlled compression ignition engine (RCCI). *International Journal of Hydrogen Energy*, *42*(7), 4548–4560. https://doi.org/10.1016/j.ijhydene.2016.12.147

[11] Kakoee, A., &Gharehghani, A. (2019, September). Comparative study of hydrogen addition effects on the natural-gas/diesel and natural-gas/dimethyl-ether reactivity controlled compression ignition mode of operation. *Energy Conversion and Management*, *196*, 92–104. https://doi.org/10.1016/j.enconman.2019.05.113

[12] Li, J., Yang, W., & Zhou, D. (2017, March). Review on the management of RCCI engines. *Renewable and Sustainable Energy Reviews*, *69*, 65–79 https://doi.org/10.1016/j.rser.2016.11.159

[13] Wang, Y., Yao, M., Li, T., Zhang, W., &Zheng, Z. (2016, August). A parametric study for enabling reactivity controlled compression ignition (RCCI) operation in diesel engines at various engine loads. *Applied Energy*, *175*, 389–402. https://doi.org/10.1016/j.apenergy.2016.04.095

[14] Dong, Yabin .Reactivity controlled compression ignition (RCCI) combustion using methanol and diesel in a single cylinder research engine, 2018 http://urn.fi/URN:NBN:fi:aalto-201810055282

[15] Reitz, R. D., &Duraisamy, G. (2015, February). Review of high efficiency and clean reactivity controlled compression ignition (RCCI) combustion in internal combustion engines. *Progress in Energy and Combustion Science*, *46*, 12–71. https://doi.org/10.1016/j.pecs.2014.05.003

[16] Lee, J., Chu, S., Min, K., Jung, H., Kim, H., & Chi, Y. (2017, October 23). Experimental investigation of diesel/gasoline dual-fuel premixed compression ignition strategies for high thermal efficiency and high load extension. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *232*(10), 1374–1384. https://doi.org/10.1177/0954407017729058

[17] Ganesh Duraisamy, Ganesh, D., &Nagarajan, G. (2019). Effect of EGR and Premixed Mass Percentage on Cycle to Cycle Variation of Methanol/Diesel Dual Fuel RCCI Combustion. https://doi.org/10.4271/2019-26-0090

[18] Jamrozik, A., Tutak, W., & Grab-Rogaliński, K. (2019, October 12). An Experimental Study on the Performance and Emission of the diesel/CNG Dual-Fuel Combustion Mode in a Stationary CI Engine. *Energies*, *12*(20), 3857. https://doi.org/10.3390/en12203857

[19] Legrottaglie, F., Mattarelli, E., Rinaldini, C. A., Savioli, T., and Scrignoli, F., “Experimental investigation on a diesel engine operated in RCCI combustion mode”, in <i>74th Ati National Congress: Energy Conversion: Research, Innovation and Development for Industry and Territories</i>, 2019, vol. 2191, no. 1. doi:10.1063/1.5138829.

[20] Kumbhar, V. S., Shahare, A., &Awari, G. K. (2021, August 1). Review on Reactivity Controlled Compression Ignition Engines: an Approach for BSVI emission Norms. *IOP Conference Series: Materials Science and Engineering*, *1170*(1), 012011. https://doi.org/10.1088/1757-899x/1170/1/012011

[21] Szamrej, G., Karczewski, M., &Chojnowski, J. (2021, September 25). A review of technical solutions for RCCI engines. *Combustion Engines*, *189*(2), 36–46. https://doi.org/10.19206/ce-142551In-Text Citation: (Szamrej et al., 2021)

[22]Erdiwansyah, R. Mamat, M.S.M. Sani, K. Sudhakar, AsepKadarohman, R.E Sardjono, An overview of Higher alcohol and biodiesel as alternative fuels in engines,Energy Reports,Volume 5,2019,Pages 467-479,ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2019.04.009.

[23]Erdiwansyah, R. Mamat, M.S.M. Sani, K. Sudhakar, AsepKadarohman, R.E Sardjono, An overview of Higher alcohol and biodiesel as alternative fuels in engines,Energy Reports, Volume 5,2019,Pages 467-479,ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2019.04.009

[24]Luo, Jianbin& Liu, Zhonghang& Wang, Jie&Xu, Hongxiang& Tie, Yuanhao& Yang, Dayong& Zhang, Zhiqing& Zhang, Chengtao& Wang, Haijiao, 2022. "Investigation of hydrogen addition on the combustion, performance, and emission characteristics of a heavy-duty engine fueled with diesel/natural gas," Energy, Elsevier, vol. 260(C).

[25] The potential role of hydrogen as a sustainable transportation fuel to combat global warming. / Acar, Canan; Dincer, Ibrahim.In: International journal of hydrogen energy, Vol. 45, No. 5, 29.01.2020, p. 3396-3406.

[26] Karczewski M, Chojnowski J, Szamrej G. A Review of Low-CO2 Emission Fuels for a Dual-Fuel RCCI Engine. Energies. 2021; 14(16):5067. https://doi.org/10.3390/en14165067

[27] Rahimi, Hadi&Jazayeri, Seyed&Ebrahimi, Mojtaba. (2020). Hydrogen energy share enhancement in a heavy duty diesel engine under RCCI combustion fueled with natural gas and diesel oil. International Journal of Hydrogen Energy. 45. 10.1016/j.ijhydene.2020.04.263.

[28] Halis, S. (2023). An Experimental Study of Operating Range, Combustion and Emission Characteristics in an RCCI Engine Fueled with Iso-Propanol/n-Heptane. Sustainability. https://doi.org/10.3390/su151410897

[29] Thippeshnaik, G., Prakash, S. B., Suresh, A., GowdruChandrashekarappa, M., Samuel, O. D., Der, O., &Ercetin, A. (2023). Experimental Investigation of Compression Ignition Engine Combustion, Performance, and Emission Characteristics of Ternary Blends with Higher Alcohols (1-Heptanol and n-Octanol). Energies. https://doi.org/10.3390/en16186582

[30] Sengupta, A., Biswas, S., & Banerjee, R. (2023). Performance-emission effect of n-butanol in Reactivity Controlled Compression Ignition regimes of biodiesel combustion. Energy Sources Part A-Recovery Utilization and Environmental Effects. https://doi.org/10.1080/15567036.2023.2253746

[31] Krishnasamy, A., Duraisamy, G., & Hossain, A. K. (2023). Investigations on reactivity controlled compression ignition combustion with different injection strategies using alternative fuels produced from waste resources. International Journal of Engine Research. https://doi.org/10.1177/14680874231179044

[32] Deresso, H., Ancha, V. R., &Nallamothu, R. B. (2023). Experimental study of triple fuel physiognomies on LDRCCI diesel engine combustion. Results in Engineering. https://doi.org/10.1016/j.rineng.2023.101451

[33] Ravi, H., &Seetharamaiah, N. (2023). Characterization of Emission-Performance Paradigm of a RCCI Engine Using Artificial Intelligent Based Multi Objective Response Surface Methodology Model Fueled with Ternary Fuel. International Journal of Ambient Energy, 1–14. https://doi.org/10.1080/01430750.2023.2206816

[34] Dwarshala, S. K. R., Kummitha, O. R., Venkatesan, E. P., Veza, I., & Samuel, O. D. (2023). A Review on Recent Developments of RCCI Engines Operated with Alternative Fuels. Energies, 16(7), 3192. https://doi.org/10.3390/en16073192

[35] Agarwal, A. K., Singh, A. P., & Kumar, V. (2022). Reactivity Controlled Compression Ignition Engine Fueled With Mineral Diesel and Butanol at Varying Premixed Ratios and Loads. Journal of Energy Resources Technology-Transactions of TheAsme, 144(2). https://doi.org/10.1115/1.4051037

[36] Algayyim, S. J. M., Wandel, A. P., &Yusaf, T. (2021). Mixtures of n-butanol and iso-butanol blended with diesel: experimental investigation of combustion characteristics, engine performance and emission levels in a compression ignition engine. 12(4), 439–448. https://doi.org/10.1080/17597269.2018.1493565

[37] Jamrozik, A., Tutak, W., & Grab-Rogaliński, K. (2021). Combustion Stability, Performance and Emission Characteristics of a CI Engine Fueled with Diesel/n-Butanol Blends. Energies, 14(10), 2817. https://doi.org/10.3390/EN14102817

[38] Noroozi, M. J., Seddiq, M., &Habibi, H. (2020). Investigation of the Effects of Diesel Injection Strategies in a Reactivity Controlled Dieseliso-Butanol Compression Ignition Engine. 10(4), 3394–3407. http://ijae.iust.ac.ir/article-1-577-en.html

[39] Ganesan, N., Masimalai, S., Ekambaram, P., &Selvaraju, K. (2020). Experimental Assessment of Effects of n-Butanol on Performance, Emission, and Combustion Characteristics of Mahua Oil Fueled Reactivity Controlled Compression Ignition (RCCI) Engine. 6(3), 345–357. https://doi.org/10.1007/S40825-020-00163-1

[40] Singh, A. P., Sharma, N., Kumar, V., & Agarwal, A. K. (2021). Experimental investigations of mineral diesel/methanol-fueled reactivity controlled compression ignition engine operated at variable engine loads and premixed ratios. International Journal of Engine Research, 22(7), 2375–2389. https://doi.org/10.1177/1468087420923451