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Performance, Combustion and Emission Analysis of Reactivity Controlled Compression Ignition Engine

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Abstract

Reactivity Controlled Compression Ignition (RCCI) is an advanced combustion technology that uses two fuels with different reactivity to improve engine efficiency and reduce emissions. In this study, the performance, combustion, and emission characteristics of an RCCI engine were analyzed using gasoline as the low-reactivity fuel and diesel as the high-reactivity fuel. The experiments were conducted by varying engine load, fuel ratio, injection timing, and exhaust gas recirculation (EGR) rate while maintaining constant engine speed. Performance parameters such as brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC), along with emission parameters like NOx, CO, HC, and smoke were evaluated. The results show that RCCI combustion can significantly reduce NOx and soot emissions while improving engine efficiency compared to conventional diesel engines. This study shows that RCCI technology has strong potential for future low-emission and high-efficiency engines.

Keywords: *RCCI Engine, Dual Fuel Combustion, Emissions, Brake Thermal Efficiency, Alternative Fuels*

1. Introduction

Internal combustion (IC) engines are widely used in transportation, agriculture, and power generation due to their high efficiency, reliability, and power output. Among the various types of IC engines, diesel engines are commonly used because of their higher thermal efficiency and durability compared to spark ignition engines. However, conventional diesel engines produce harmful emissions such as nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC), which cause environmental pollution and health hazards. Due to strict emission regulations and depletion of fossil fuels, researchers are focusing on advanced combustion technologies that can improve engine efficiency while reducing emissions. Reactivity Controlled Compression Ignition (RCCI) is an advanced low-temperature combustion technology that uses two fuels with different reactivity levels to control the combustion process. In RCCI engines, a low-reactivity fuel such as petrol, gasoline, ethanol, or natural gas is injected through the intake port to form a premixed air–fuel mixture, while a high-reactivity fuel such as diesel or biodiesel is directly injected into the combustion chamber near the end of the compression stroke. This creates a reactivity gradient inside the cylinder, which helps to control ignition timing and heat release rate more effectively than conventional combustion methods.

The RCCI combustion process produces low-temperature and homogeneous combustion, which significantly reduces nitrogen oxide and soot emissions while maintaining high brake thermal efficiency. RCCI engines also provide flexibility in fuel selection and can operate with alternative and

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renewable fuels such as biodiesel, alcohol fuels, and hydrogen-enriched fuels, making them a promising technology for future clean engines. The main objective of this research is to analyze the performance, combustion, and emission characteristics of an RCCI engine under different operating conditions. Parameters such as fuel reactivity ratio, injection timing, exhaust gas recirculation (EGR), engine load, and engine speed were considered to evaluate their effects on engine performance and emissions. The study aims to demonstrate that RCCI combustion can achieve higher efficiency with lower emissions compared to conventional diesel engines. [1-3]

2. Methodology

Figure 1 Location

In this study, an experimental investigation was carried out on a Reactivity Controlled Compression Ignition (RCCI) engine using a dual-fuel strategy. Two fuels with different reactivity were used to achieve controlled combustion. Gasoline was used as the low-reactivity fuel (LRF) due to its high octane number, while diesel blended with rice bran biodiesel was used as the high-reactivity fuel (HRF). The rice bran biodiesel blend was prepared to study the effect of biodiesel on engine performance, combustion, and emission characteristics in RCCI mode. Figure 1 shows Location A single-cylinder compression ignition engine was modified to operate in RCCI mode. The low-reactivity fuel (gasoline) was supplied through a port fuel injection system to form a premixed air–fuel mixture inside the intake manifold, while the high-reactivity fuel (diesel–rice bran biodiesel blend) was directly injected into the combustion chamber near the end of the compression stroke. The compression ratio of the engine was maintained constant at 17.5:1 throughout the experiments. To analyze the performance of the RCCI engine, several operating parameters were varied during the experiment. These included the fuel reactivity ratio (LRF/HRF), injection timing of the high-reactivity fuel, exhaust gas recirculation (EGR) rate, and engine load, while the engine speed was kept constant. These parameters significantly influence combustion characteristics, fuel efficiency, and emission formation. The experimental setup was equipped with various measuring instruments. An in-cylinder pressure sensor and crank angle encoder were used to study combustion characteristics such as cylinder pressure and heat release rate. An emission analyzer was used to measure exhaust emissions such as nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and smoke opacity. A fuel flow meter was used to measure fuel consumption for calculating brake specific fuel consumption. During the experiment, the engine was first started and allowed to reach steady operating condition. The engine was then operated in RCCI mode using gasoline and diesel–rice bran biodiesel blend. The load on the engine was varied gradually while maintaining constant speed, and readings were recorded at each load condition. Performance parameters such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and exhaust gas temperature (EGT) were recorded along with emission parameters. Finally, the collected data were analyzed and compared with conventional diesel engine operation to evaluate the improvement in engine efficiency and reduction in emissions achieved by RCCI combustion using rice bran

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biodiesel blend.

3. Results

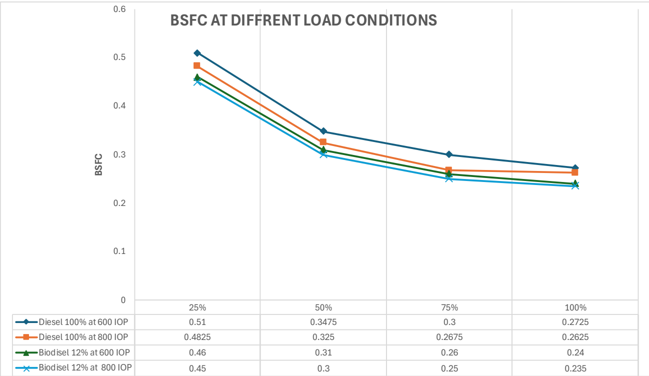

Figure 2 BSFC v/s Load

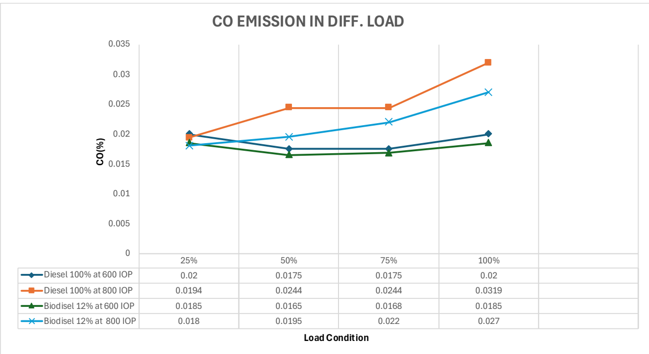

Figure 3 CO v/s Load

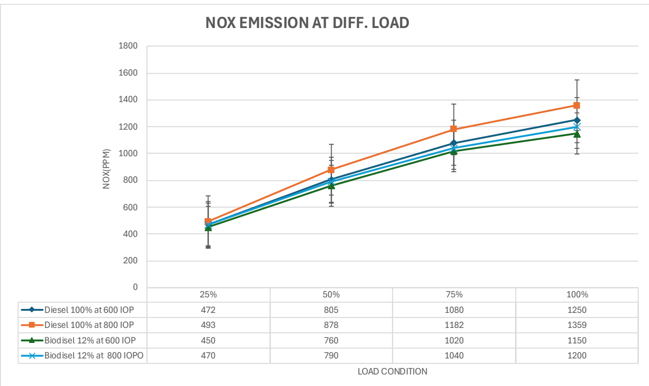

Figure 3 NOx v/s Load

4. Discussion

BSFC decreases with increase in load because engine efficiency increases at higher loads. At low load, incomplete combustion and heat losses result in higher BSFC. As load increases, combustion improves due to higher temperature and pressure, leading to lower BSFC. The RCCI operation using gasoline and diesel–rice bran biodiesel blend shows better fuel utilization and lower BSFC at higher loads. From Fig 2.2 , it can be concluded that CO emissions are almost constant at different loads for both diesel and B12 blend. However, the B12 blend shows slightly lower CO emissions compared to diesel because the rice bran biodiesel contains oxygen which helps in better combustion. Overall, the B12 blend performs slightly better and helps in reducing harmful emissions From fig.2.3, it seems that NOx emissions increase with engine load and injection pressure, but the B12 blend produces lower NOx emissions than diesel due to lower peak combustion temperature in RCCI combustion. Therefore, the B12 blend is more environmentally friendly in terms of NOx emissions. [4-5]

Conclusion

The RCCI engine using B12 rice bran biodiesel blend showed improved combustion and reduced CO, HC, and smoke emissions with controlled NOx emissions. Hence, B12 blend can be used as an alternative fuel for cleaner and efficient engine operation. [6-10]

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