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Experimental Optimization of Reactivity Controlled Compression Ignition Combustion with Cost Effective Electronic Fuel Injection in a Light Duty Diesel Engine

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Abstract

In order to control exhaust emissions from Internal Combustion (IC) engines, ever-tighter international legal standards and excessive tax penalties have been introduced globally due to concerns about the depletion of oil reserves, rising energy costs, and the environmental effects of greenhouse gas emissions. Low-Temperature Combustion (LTC) techniques are currently the main focus of researchers' efforts to develop more effective internal combustion engines with alternate combustion strategies employing oxygenated renewable alternate fuels. A fuel-flexible enhanced LTC technology called Reactivity Controlled Compression Ignition (RCCI) aims to maximize engine efficiency while reducing engine exhaust pollutants. In this study, a non-road, four-stroke, single-cylinder, water-cooled production diesel engine (Kirloskar AV1) was appropriately converted to operate at a rated speed of about 1500 rpm under RCCI combustion mode. The primary goal of the current study was to experimentally examine the potential applications of higher alcohol n-butanol, Karanja biodiesel mix B20, and alternative fuels in a dual fuel RCCI combustion engine. Bioenergy will support the rural economy and has the ability to increase the world's future energy needs. The test engine's intake manifold was altered to provide room for an exhaust gas recirculation (EGR), port fuel injector, and air preheater. Additionally, by integrating a high-pressure solenoid injector, a common rail with a Pressure Control Valve (PCV) and Rail Pressure Sensor (RPS), fuel filters, a low-pressure electrical fuel feed pump, crank position sensor, cam position sensors, and an open Electronic Control Unit (ECU) with the test engine, the mechanical fuel injection system was replaced with a common rail direct injection system.

Keywords: Internal Combustion, Reactivity Controlled Compression Ignition, Pressure Control Valve.

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Introduction

Vehicle makers must use a number of technologies to fulfil these fuel efficiency standards while staying inside Environmental Protection Agency (EPA) emission regulations. Improved fuel efficiency of internal combustion engines, especially diesel engines, is predicted to be a key area of development. As can be seen, transportation contributes 13% of world GHG emissions (Jo et al., 2019). The most popular types of ICEs utilized in the transportation sector are diesel and gasoline engines. However, there were no notable advances because the updated model that was given was in derivative form. Another problem we've talked about is the increased discrepancy between the sliding mode function and the real system data. Therefore, accurate weight functions may help close that gap for better predictions, but they also run the danger of overfitting, therefore a good regularization function is crucial. On the one hand, the neural networks' shortcomings for sliding mode functions still exist. Conversely, the literature's sliding mode functions frequently call for a great deal of design variable adjustment (Liu et al., 2019). Regretfully, the literature hasn't offered much advice on how to choose these design variables accurately using the greatest knowledge currently available. Current system models still require a great deal of refinement, even though neural network-assisted sliding mode control is outperforming conventional techniques (Thomas et al., 2020). Progress and Recent Trend shown in Fig. 1.

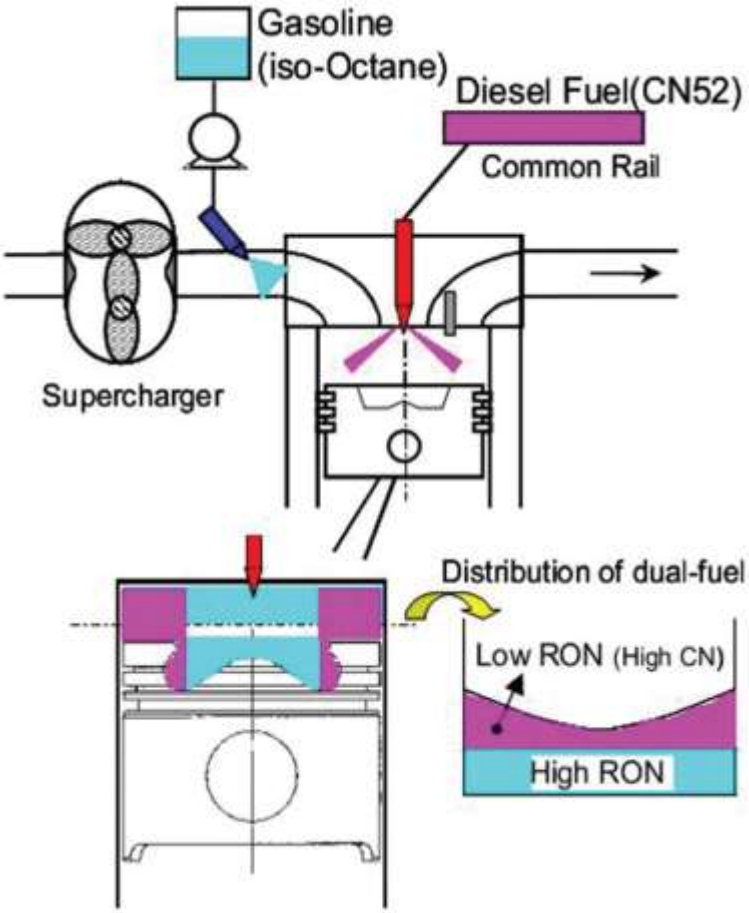

Fig. 1: Progress and Recent Trend

There are already many auto-ignition correlations for diesel combustion concepts, including conventional diesel combustion, homogeneous charge compression ignition (HCCI), and partially premixed compression ignition (PCCI). However, these correlations ignore the effect of DI and only take into account the physical delay time 7 or are valid for a single fuel. In HCCI, the combustion chamber is filled with a homogenous mixture of fuel and air at consistent temperatures and pressures. In order to meet the strict pollution standards around the world, internal combustion engines and fuel designs have evolved over time. Diesel engines are more desirable due to their increased dependability and efficiency (Liu et al., 2019). The inherent properties of diesel engines will result in significant levels

of smoke and NOx. This paper narrates the importance of the RCCI, and internal combustion engine research is on reducing fuel usage in order to reduce greenhouse gas emissions.

Review of Literature

The majority of state-of-the-art sliding mode controllers employ clever strategies like fuzzy sets and neural networks. This is mostly due to the fact that other probabilistic models, including partial derivatives and composite controllers, have computational efficiency problems and perform poorly in unexpected problem domains. Neural networks have demonstrated exceptional performance among the many intelligent controllers for efficient sliding mode control, particularly in robotic systems such as milling head processes. They have their own set of drawbacks, despite their advantages, which include simplicity, real-time application appropriateness, and accurate learning without requiring prior information (Jain et al., 2021). These include a discrepancy between the problem space and the properties of the system, challenges in adopting accurate weight functions, and regularization issues. These difficulties are related to one another. For example, precisely adjusting weight functions helps improve the network's learning process.

In 2016, Yueneng Yang and Ye Yan introduced a ground breaking approach called the neural network approximation-based non-singular terminal sliding mode control (NN-NTSMC) scheme (Pandian & Anand, 2018). Their method took into account indefinite disturbances by employing hysteretic chaotic neurons and networks (Ganesh et al., 2019). They effectively controlled the state of the neurons and the neural network, leading to the precise attainment of the desired state through fuzzy SMC. Overall, this technique demonstrated how neuron states or neural networks can converge on the optimal point of the function being optimized. Deterministic neural networks are known for solving function approximation problems, but this approach deftly addressed optimization problems by utilizing the network model.

Materials and Methods

Two fuels with varying reactivity are needed for RCCI combustion in order to regulate the combustion. Reactivity is related to the fuel's cetane number. Fuels that resemble diesel are referred to as high reactivity fuels, whereas fuels like gasoline are referred to as low reactivity fuels. In order to improve control over combustion, the RCCI mode of operation injects low-reactivity fuels during the engine's intake stroke and high-reactivity fuels late in the compression stroke. This changes the global reactivity of the fuels inside the engine cylinder while it is operating. By combining two distinct reactivity fuels in-cylinder, we can improve emissions and fuel conversion efficiency. In order to feed gasoline and diesel-like fuels at the proper time and quantity, the test engine's cylinder head was modified to accommodate electronically controlled low-pressure port fuel injectors (PFI) and high-pressure direct injectors (Garcia et al., 2020).

The non-edible Karanja (Pongamia Pinnata) is a medium-sized tree, which can grow to adults in five years and can survive in heat, drought, salinity, and forests. It is a monotypic genus seen in all parts of India in coastlands, river banks and requires overhead sunlight in the early stages. Karanja tree yield varies from 9 to 90 kg and the fruit can survive for one year. But in most of the places, its seeds are left unused though it can give an oil yield of 27 to 39% and the oil yield per year is about 2 to 4 t/hectare. Control valves and hot and cold exhaust gas recirculation (EGR) loops are added to the exhaust system. To improve fuel spray dispersion, the high-pressure solenoid-operated injector is mounted along the cylinder axis using a newly designed, custom-made cylinder head in place of the current one. For injecting high reactive fuel, a highly adaptable common rail direct fuel injection system takes the place of the current mechanical fuel injection system. To inject low reactive fuel, a low-pressure port fuel injection system is placed in the intake manifold close to the intake port (Garcia et al., 2020).

Results and Discussion

This section presents the experimental findings from the investigation of the RCCI combustion engine's performance, emission characteristics, and combustion utilizing the n-butanol and Karanja biodiesel blend (B20). In the engine, the RCCI tests were run at 100% (3.7 kW), 75% (2.78 kW), and 50% (1.85 kW) loads. Throughout the trials, the PFI injection pressure of 3 bar and the CRDI pressure of 400 bar were kept constant. The parametric studies on the variation of PFI mass fractions, intake charge temperature, EGR, injection timing, and multiple injections of HRF were performed to identify the best operating points. Total Fuel Consumption shown in Fig. 2.

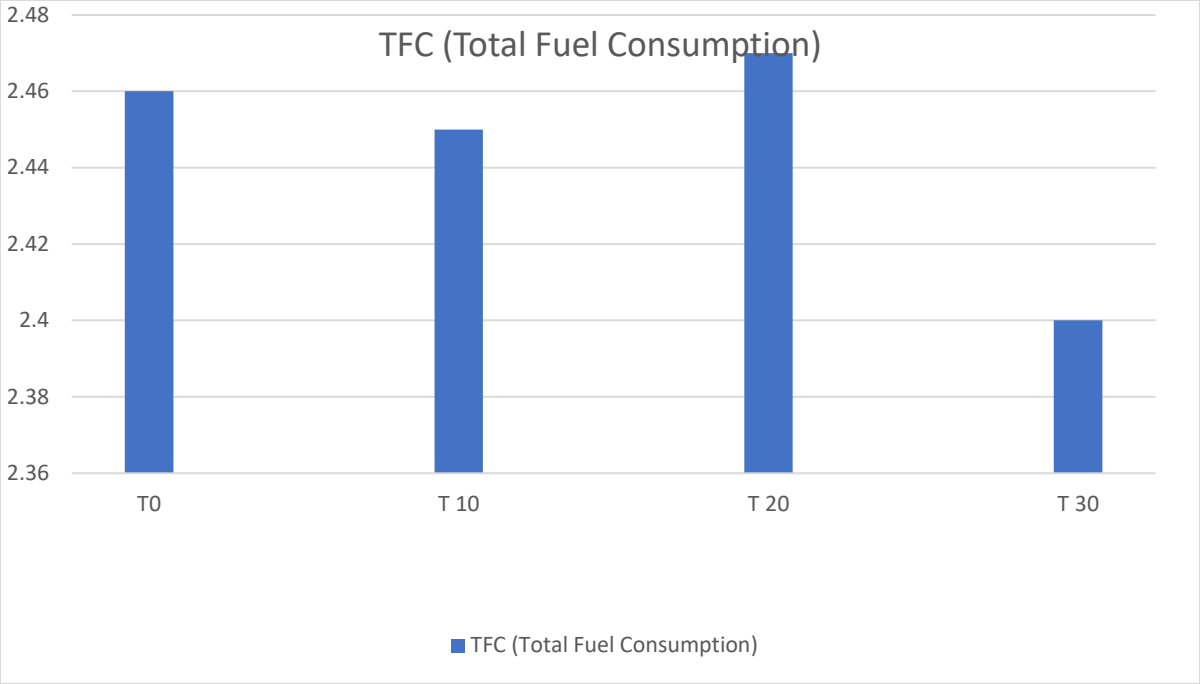

Fig. 2: Total Fuel Consumption

The image depicted shows the TFC of the RCCI engine with Load 20 nm and Brake power 3.14 for four different fuel composition. The graph shows that the TFC of T30 is the minimum and TFC of T30 is maximum. The above reading clearly depicts the change in total fuel consumption of the four types of fuel composition.

The early injection angle allowed more time for better charge preparation and resulted in the reduction of smoke. Further advancement of injection angle has resulted in poor combustion leading to increased smoke emission. Crank Angle shown in Fig. 3.

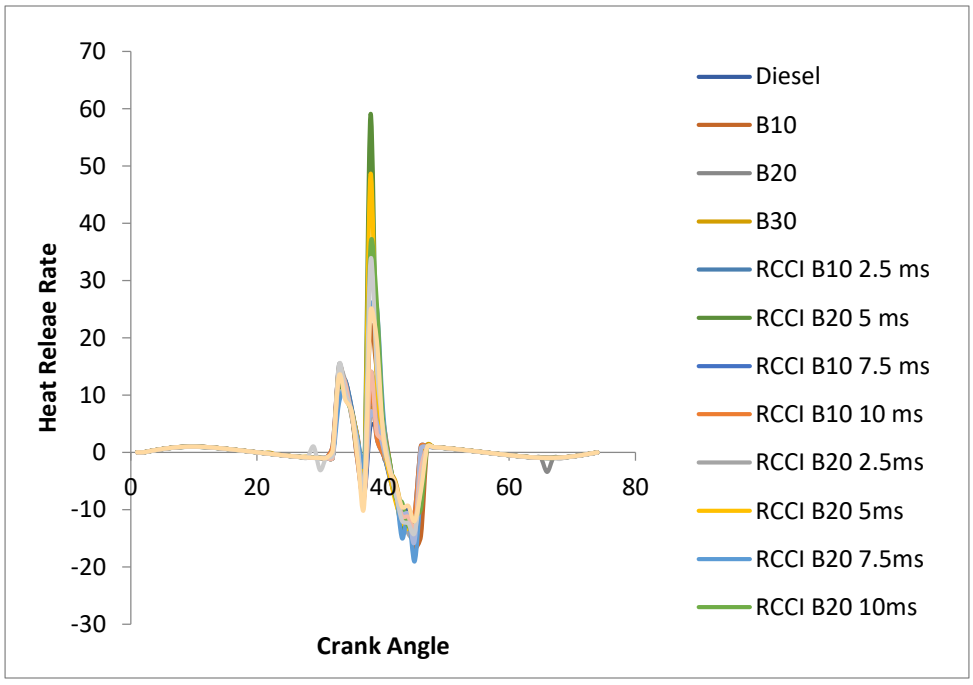

Fig. 3: Crank Angle

Advancing SOI 2 resulted in more fuel accumulation during longer ignition delay, leading to excessive NO formation due to higher heat release rate, and in-cylinder temperature. The CO and HC emission showed marginal changes similar to the SOI 3 sweep. By examining all the above results, the acceptable SOI 2 injection is fixed at 27° bTDC.

Conclusion

The findings showed that, under all load situations, RCCI operation offers greater thermal efficiency and lower emissions (NO and soot) than CDC mode. Enabling the RCCI strategy with alternative fuels saves a lot of conventional fossil fuel used in non-road diesel engine segment. The following are the main findings for the load situations tmethanol/diesel (M/D) dual-fuel RCCI operation were determined to be 65%, 50%, and 45% at 10% load, respectively. G/D and IB/D of BTE under RCCI combustion increased by 5% and 1%, respectively, when 70%, 60%, and 50% premixed energy fractions were employed for G/D, IB/D, and M/D at 25% load as opposed to CDC.

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