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The Impact of Blends and Comparison of Diesel, Ethanol and Microalgae on the Performance, Combustion, and Emissions of a CRDI Engine.

[1]Katravath Bicha*, [2]Boda Hadya

[1]*Research scholar, Department of Mechanical Engineering, Osmania University, Telangana, India.*

[2]*Professor, Department of Mechanical Engineering, Osmania University, Telangana, India.*

Abstract:

To assess the impact of hybrid fuels containing microalgae, ethanol and diesel blends on combustion, performance, and emissions, experiments were conductedusing a single-cylinder, four-stroke, naturally aspirated diesel engine. This engine, which was water-cooled and featured direct injection, simulated various load conditions using thermodynamic engine simulation software. The findings indicate that hybrid fuel blends with ethanol exhibit higher engine brake torque (EBT) and lower exhaust gas temperatures compared to the base fuel. Microalgaebased hybrid fuels contribute to increased cylinder pressure. Moreover, hybrid fuel blends prolong the ignition delay period and combustion duration. Notably, the addition of spirulina microalgae reduces the ignition delay period in microalgae-diesel blend fuel. Regarding emissions, spirulina microalgae emulsions decrease specific particulate matter (PM), soot, and smoke emissions,except for nitrogen oxides (NO_X), while carbon dioxide (CO_2) emissions are higher relative to the base fuel.

Keywords: Diesel engine, Biodiesel, Hydrogen, Injection pressure

1. Introduction:

Global energy demand has surged due to rapid population growth and socioeconomic development. Currently, nearly half of the carbon dioxide emittedfrom burning fossil fuels remains in the atmosphere, exacerbating global warmingbecause it is not absorbed by plants or oceans. Internal combustion engines, known for their efficiency and adaptability, dominate transportation. Diesel engines, particularly prevalent in this sector, excel in generating torque with highcompression ratios compared to gasoline engines. Despite their advantages, dieselengines emit lower concentrations of unburnt hydrocarbons and carbon monoxidethan spark-ignition engines due to their operation with a lean air/fuel mixture. However, they still release pollutants such as unburnt hydrocarbons, carbon monoxide, nitrogen oxides, particulates, sulfur oxides, and lead, which pose health risks and contribute to environmental issues like climate change, acid rain,ozone depletion, and photochemical smog. Given the finite nature of oil reserves,much of the world must rely on imports to meet energy needs, raising concerns about potential depletion and associated crises. This scenario, along with rising fuel costs and environmental harm from emissions, has spurred global efforts to develop renewable fuels as alternatives to conventional hydrocarbon fuels.

2. Literature Review:

Zuo et al.[1] investigated the combustion efficiency of hydrogen-powered micro-combustion furnaces, focusing on achieving higher efficiency for micro- combustion chamber applications. Han et al.[2] summarized experimental and simulation studies on various adsorbent materials used to control hydrocarbon (HC) emissions during cold

starts in gasoline engines. Wu et al.[3] compared thecombustion, efficiency, and emission characteristics of different fuel blends (B30,E30, ABE30, and G100) in stoichiometric conditions, finding ABE30 to exhibit flame retardant ability and superior performance in various aspects. Kanth et al.[4] studied the effects of hydrogen enrichment with a blend of honge biodieseland diesel on compression ignition engines, analyzing performance, combustion, and emission characteristics. Zuo et al.[5] found significant improvement in thermal efficiency when injectors were used in an innovative micro-planarcombustion chamber. Li et al.[6] conducted an arithmetical study comparing theperformance of ribbed and rectangular microburners under different hydrogen flow rates and equivalent ratios, providing insights for optimizing micro- incinerators. Kanth et al.[7] attempted hydrogen enrichment with pure diesel (ND) and rice bran biodiesel (RB20) in diesel engines, investigating the effects on engine performance and emissions. Jiaqiang et al.[8] experimentally studied the performance and economic characteristics of diesel engines with and withoutvariable injector turbochargers under various conditions. Jiaqiang et al.[9] established an optimal microwave energy consumption model for minimizing energy consumption in the mixed regenerative heating phase of diesel particulate filters, using an adaptively scalable chaos immunity algorithm. Koley et al.[10] successfully cultured Scenedesmus accuminatus microalgae in outdoor ponds and greenhouses using low-cost agricultural fertilizer, aiming to explore the effect ofopen injection pressure variation on diesel engines running on a mixture of hydrogen and biodiesel. Each study contributes to the understanding of various aspects of combustion efficiency, emission control, and performance optimization in engines using alternative fuels and combustion technologies.

3. Experimentation:

The current study focuses on analyzing a water-cooled, single-cylinder, CRDI four-stroke diesel engine operating at rated speeds and outputs of 3000 rpm and 9 hp, respectively. The experimental setup, depicted in Figure 1, includes various components typical of CRDI engines, such as a high-pressure fuel pump, pressure regulator, common piping, rail pressure sensor, and fuel injectors, all interfacingwith an electronic control unit (ECU). Charging is managed by a water-cooled eddy current dynamometer, while a crankshaft angle sensor measures crankshaftrotation. Cylinder pressure is monitored via a piezoelectric pressure transducer attached to the cylinder head. A data acquisition system collects pressure signals,allowing for the observation of combustion parameters like the heat release rate.Additionally, temperatures of inlet and outlet water, fuel, engine oil, intake air, and exhaust gases are measured using type K thermocouples. Exhaust gastemperature (EGT) is determined with a thermoelectric sensor pair located near the cylinder exhaust pipe. An AVL analyzer and a smoke meter assess emissionssuch as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), andsmoke levels. Hydrogen supply components include pressure regulators, flow meters, hydrogen cylinders, flow control valves, flame arresters, and fire traps.

Figure1: Experimental Setup of CRDI duel fuel Engine

Table 1. Specifications of the Test Rig

S.No	Description	Specifications
1	Make	Mahindra and Mahindra
2	Engine Capacity (cc)	625
3	Number of cylinders	1
4	Application	Automotive (Multi-speed)
5	Number of Strokes	4
6	Compression Ratio	18:1
7	Bore (mm)	93.0 to 93.018
8	Stroke Length (mm)	92
9	Ignition	Compression Ignition
10	Max. Power @ RPM	9 HP @ 3000 RPM
11	Max. Torque @ RPM	30 NM @ 1800 RPM
12	Cooling System	Water Cooled

4. Results and Discussions

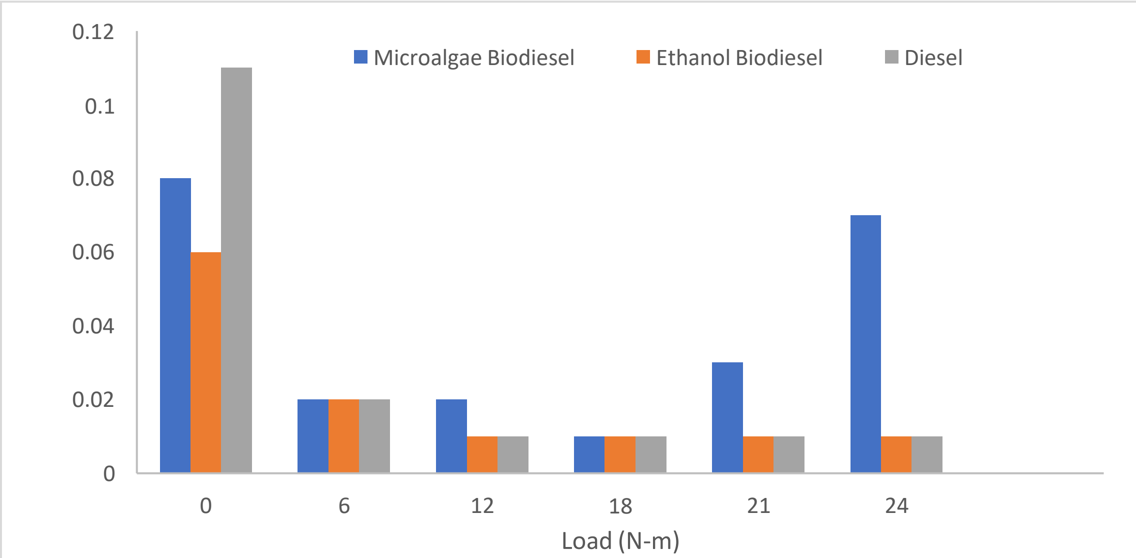
4.1 Emission Characteristics:

Carbon monoxide (CO):

Incomplete combustion of fuel results in carbon monoxide (CO) emissions, whichare influenced by factors such as the air/fuel ratio and engine temperature. Figure2 shows the CO emissions of various fuels of B30 at 1800 rpm at varying loadingconditions at 750bar injection pressure. The findings indicate that increasing theproportion of biodiesel in the fuel blend can reduce CO emissions, especially at lower engine speeds. This reduction is due to the oxygen content in biodiesel's chemical composition, which helps convert CO to CO_2, thereby lowering CO emissions. At higher engine speeds, where intake volumetric efficiency decreases, the extra oxygen in the fuel mix becomes even more significant. As aresult, the high-quality biodiesel produced in this study showed a considerable reduction in CO emissions, as illustrated in the figure.

emissions

Figure 2: CO em B30 various biodiesel & loads at 750 bar injectionpressure



Carbon dioxide (CO_2)

Figure 3 displays the CO_2 emissions for B30 biodiesel blends under various loadsat an engine speed of 1800 rpm with an injection pressure of 750 bar. The data reveals that at a load of 24N, CO_2 emissions are 0.45% lower with ethanol biodiesel compared to microalgae biodiesel, and 0.36% lower compared to pure diesel. These differences can be attributed to the oxygen content in biodiesel fuel,which facilitates a more complete combustion process in fuels containing biodiesel compared to pure diesel fuel.

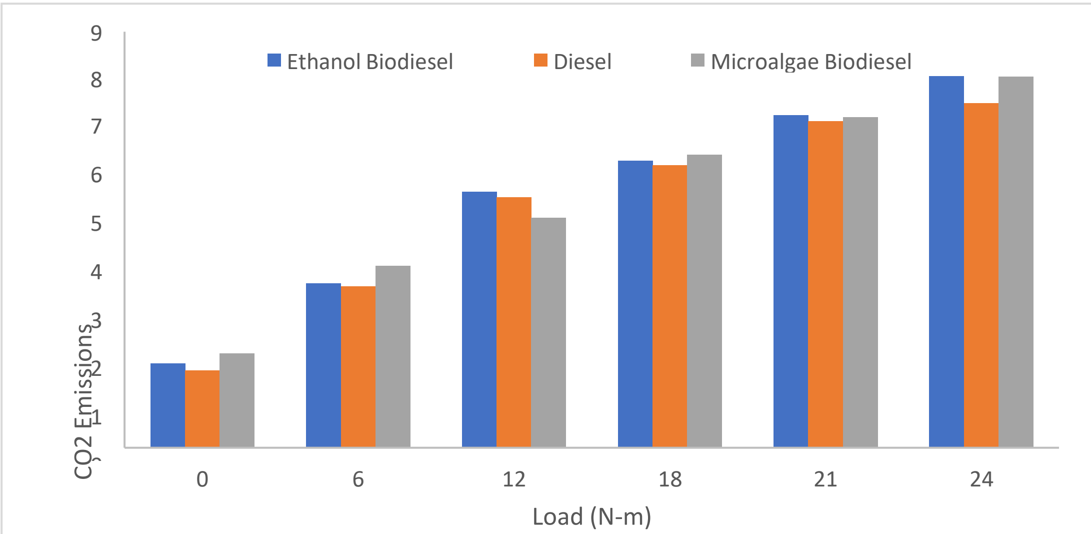


Figure 3: CO_2 emissions at B30 various biodiesel & loads at 750 bar injectionpressure

Hydrocarbons (HC):

The fraction of unburned hydrocarbons (HC) in engine exhaust gases serves as ametric for assessing fuel combustion quality, increasing when combustion is incomplete. Figure 4 depicts HC emissions for B30 fuel at 700 bar injection pressure across various engine loads for different Biofuels. The findings reveal significant reductions in HC emissions for microalgae and ethanol biodiesel compared to pure diesel at 1800 rpm, they further rise to 9.50% and 18.18%, respectively. The presence of unburned HC in combustion byproducts is primarily attributed to reduced combustion temperatures and insufficient oxygen to facilitate complete combustion. However, due to the oxygen content in biodieselfuel, blended fuels result in lower HC pollutant fractions compared to pure diesel.

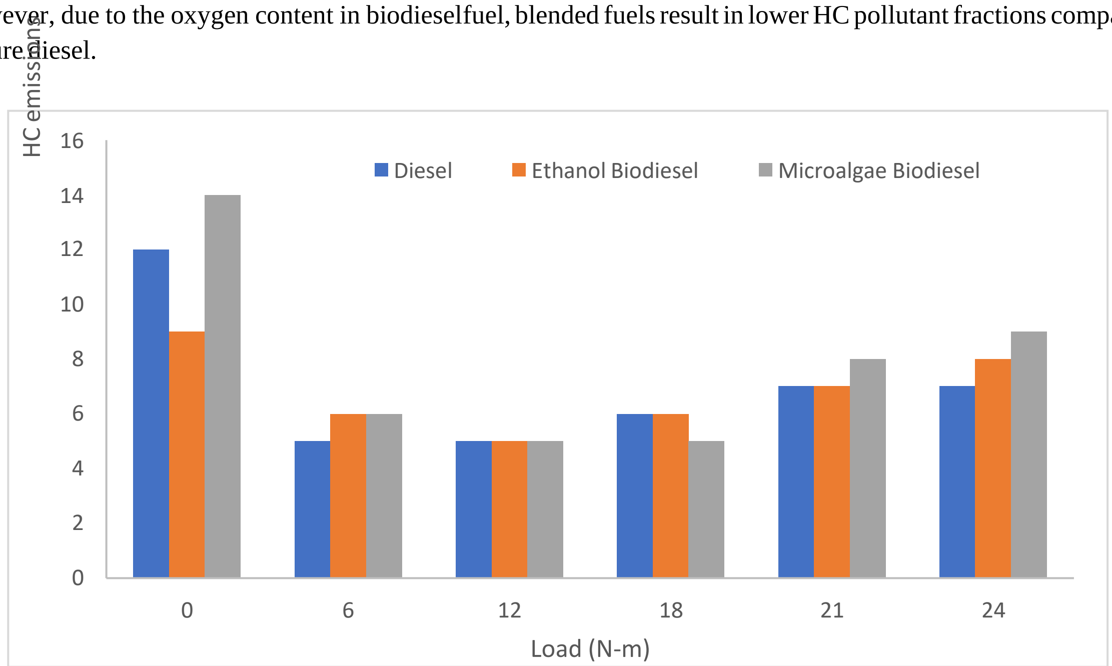


Figure 4. HC emissions at B30 various biodiesel & loads at 750 bar injectionpressure

Nitrogen Oxides (NOx):

Figure 5 displays the NOx emissions for the examined fuels across various operational conditions of the engine. The average values indicate that NOx emissions are nearly identical at different loading stages for various biodiesels. However, at a load of 24N, microalgae biodiesel emits less NOx than diesel. Theproduction of NOx is influenced by the combustion interval in 2p crank angle, where shorter intervals result in lower NOx production. Additionally, the fuel cetane number exhibits an inverse relationship with combustion delay, meaning that fuels with higher cetane numbers experience less combustion delay.

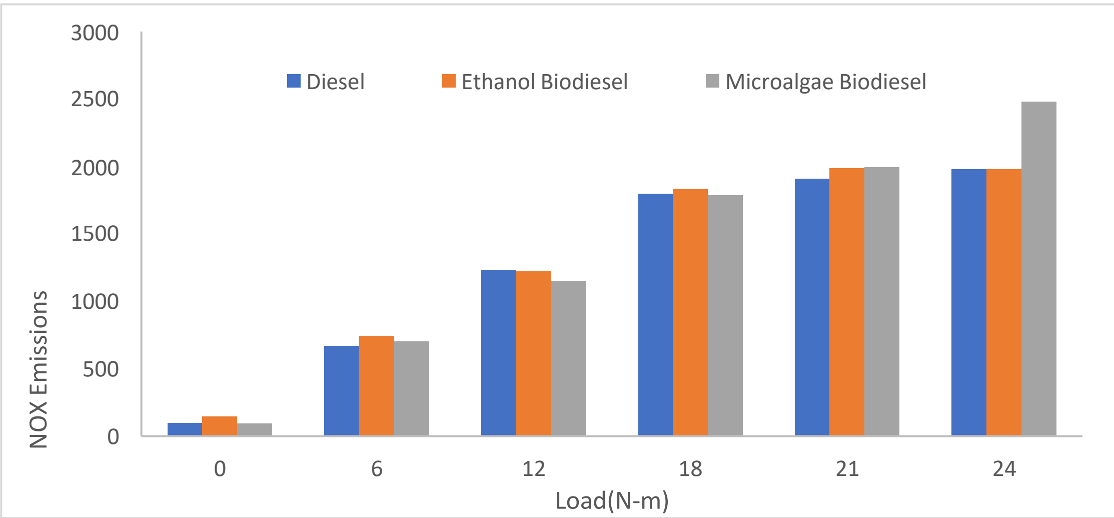


Figure 5. NOx emissions at B30 various biodiesel & loads at 750 bar injectionpressure

4.2 Performance Characteristics:

Brake-Specific Fuel Consumption (BSFC):

Brake-specific fuel consumption (BSFC) measures the fuel efficiency of any prime mover using fuel to produce rotational or shaft power. The BSFC of an engine is influenced by factors such as rotational speed, compression ratio, gear ratio, and engine volume. Increasing the engine's rotational speed typically leadsto a decrease in fuel consumption due to reduced heat loss. However, once it reaches its minimum, fuel consumption begins to rise again due to significant friction losses at higher speeds. The impact of engine load on BSFC mirrors the effect of engine speed on BSFC.

Figure 6 illustrates the variations in engine BSFC with engine speed and load across three different biodiesels. As shown, BSFC significantly decreases with added load on biodiesel fuel, primarily due to biodiesel's lower calorific value (44,920 kJ/kg) compared to pure diesel (45,500 kJ/kg). Specifically, for diesel, ethanol biodiesel, and microalgae biodiesel, BSFC values are nearly equal at a load stage of 24 kg. At 1800 rpm, the average BSFC value at a 24 kg load is 26.4g/kWhr, which is lower than that of pure diesel.

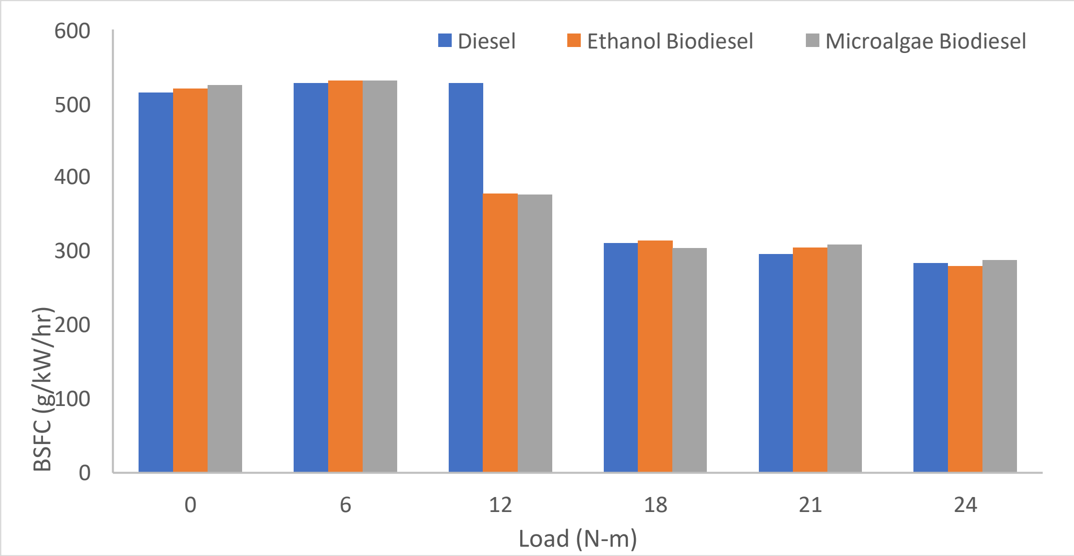


Figure 6. BSFC at B30 various biodiesel & loads at 750 bar injection pressure

Brake Thermal Efficiency (BTE):

Brake thermal efficiency is a critical metric for assessing engine performance andis widely employed to gauge the efficacy of alternative fuels, including biodiesel.Biodiesel, composed of fatty acid methyl esters (FAMEs), has distinct properties compared to conventional diesel fuel. The molecular structure of FAMEs influences combustion characteristics such as ignition delay, combustion

duration, and heat release rate, which in turn affect brake thermal efficiency. Additionally, variables such as engine load, speed, injection timing, and injectionpressure can also influence brake thermal efficiency in biodiesel engines. Notably, biodiesel's higher oxygen content can lead to more complete combustion, thereby enhancing brake thermal efficiency.

As depicted in Figure 7, brake thermal efficiency ranges from approximately 30%to 35% across all biodiesels.

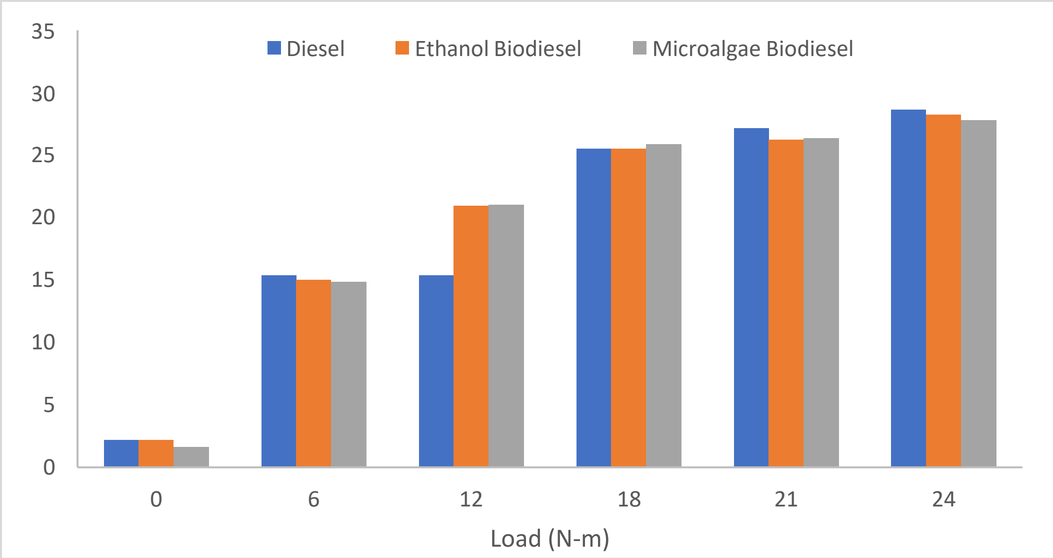


Figure 7. BTE at B30 various biodiesel & loads at 750 bar injection pressure

5. Conclusion:

In conclusion, the experimentation at 750bar injection pressure on B30 various biodiesels involved varying loads (0, 6, 12, 18, 21, 24 N-m) The summarized results are as follows: Brake thermal efficiency ranges from approximately 30%to 35% across all biodiesels. BSFC values are nearly equal at a load stage of 24 kg. At 1800 rpm, the average BSFC value at a 24 kg load is 26.4 g/kWhr, whichis lower than that of pure diesel which is favorable. Additionally, NOx emissionsare significantly lower at 25°. Furthermore, CO, CO2, and HC emissions are reduced at 20°. The findings indicate that hybrid fuel blends with ethanol exhibithigher engine brake torque (EBT) and lower exhaust gas temperatures comparedto the base fuel. Microalgae based hybrid fuels contribute to increased cylinder pressure.

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