Investigating The Performance and Emission of Biodiesel

Molleti Rajesh[1], Adduri S S M Sitaramamurty[2]
Research Scholar, Department of Mechanical Engineering, Aditya University, Surampalem, Andhra Pradesh, India[1], E-mail: rajeshmolleti@adityauniversity.in
Assistant Professor, Department of Mechanical Engineering, Aditya University, Surampalmem, Andhra Pradesh, India.[2], E-mail: assms.murthy@adityauniversity.in

Abstract
There is a great demand for the fossil fuels like petroleum products. By using the fossil fuels the emissions like smoke, NOx is high. In order to replace the fossil fuels, now-a-days researchers are moving for alternative fuels to improve the performance and lower the emissions. One of the most efficient ways to achieve this isby using the concept of RCCI engines. The primary fuel used is high viscous i.e., Micro Algae biodiesel with the combination of Di - Methyl Carbonate (DMC) and Diesel. The secondary fuel used is Pentanol i.e., Low viscous fuel. The engine can be run with the dual fuel RCCI mode to study and analyze the combustion, performance and emission characteristics.

Keywords: Combustion, Di Methyl Carbonate, Emission, Performance, , Pentanol, Micro algae Biodiesel, Reactivity controlled compression ignition.

I.INTRODUCTION

Global warming and air pollution are among the most severe consequences of modern industrialized society. Rapid industrialization and urbanization have contributed to making our environment increasingly unhealthy, not just for us but also for future generations. With the global vehicle population growing rapidly—particularly in India, which has one of the fastest-growing automotive industries—the limitations of traditional fossil fuels are becoming increasingly apparent **[1].** Today, crude oil depletion and stricter emission regulations present major challenges for the automotive sector. The high demand for fossil fuels like crude oil and petroleum-based products leads to increased emissions, including smoke and nitrogen oxides (NOx). To address these challenges, researchers are turning their attention to alternative fuels **[2].** There are several motivations behind the shift to alternative fuels: reducing harmful emissions, lowering fuel costs, mitigating global warming, promoting domestic fuel production, improving energy efficiency, and enhancing environmental sustainability.

One of the promising combustion technologies is Reactivity Controlled Compression Ignition (RCCI), which allows flexible control over combustion phases and enables the use of fuels with different reactivities **[3].** This flexibility supports dual-fuel strategies, combining both liquid and gaseous fuels. Liquid fuels in RCCI typically include methanol, ethanol, n-butanol, and dimethyl ether, while gaseous fuels include natural gas (NG), hydrogen (H_2), and ammonia (NH_3). Among these, NG is considered one of the most viable alternatives due to its clean-burning nature, abundant availability, large storage potential, and low cost. Hydrogen offers additional benefits such as wide flammability limits, high laminar flame speed, greater energy content, and low ignition energy. These properties have made NG and H_2 the focus of extensive research.

II.LITERATURE SURVEY

As shown by Tiwari et al. (2024), Tiwari and his team, used microalgae fuel blends, with SiO_2 nano additives to evaluate the power output and emissions of a diesel engine. In the study with RSM and Taguchi methods used to enhance the performance of the engine and minimize emissions **[4].** The use of SiO_2 nanoparticles resulted in enhanced combustion efficiency and thus better performance metrics and lower emissions.

Elumalai & Ravi, 2023, Subsequently, they investigated the trinary fuel blend of hydrogen, ammonia, and biodiesel in an RCCI engine. In their experimental studies, they showed that a fuel blend of conventional and cetane-less fuels could effectively decrease the reliance on fossil fuels, improve engine performance and especially reduce emissions

[5]. Elumalai and Ravi (2022), experimentally investigated the use of ammonia and algal biodiesel as a means of reducing carbon emissions in an RCCI engine. Therefore, they applied RSM to optimize the fuel blend and achieved Brake Thermal Efficiency (BTE) of 35.13 % and Brake Specific Energy Consumption (BSEC) of 10.84 MJ/kWh. Moreover, hydrocarbon (HC) emissions and best embedded emissions of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), smoke and hydrocarbon (HC) emissions were reduced by 44%, 32%, 48%, 55%, and 66% respectively when compared to conventional biodiesel combustion **[6].**

Athmakuri Ashok and S.K. Gugulothu (2022) investigated RCCI engine performance using Jatropha oil as the high reactivity fuel and 1-pentanol as the low reactivity fuel. Experiments were conducted on a modified, water-cooled single-cylinder engine at a constant speed of 2000 rpm under medium and full load conditions. Biodiesel (B20), derived from Jatropha oil through transesterification, was directly injected into the combustion chamber. Tests at varying proportions helped determine the optimal blend of biodiesel and 1-pentanol. Results were compared under identical conditions with standard diesel **[7].** The study recorded a maximum 2.5% improvement in thermal efficiency using the 1-pentanol-biodiesel blend. Additionally, smoke opacity and NO emissions were reduced by 7.82% and 3.42%, respectively. The findings demonstrate that the 1-pentanol-biodiesel combination can effectively replace conventional diesel in RCCI engines, offering improved efficiency and lower emissions.

III.MATERIALS AND METHODS

The materials used in this experiment include Microalgae oil, Pentanol, and Dimethyl Carbonate (DMC).

3.1 Micro Algae oil & Biodiesel cultivation

Microalgae oil is extracted from algae grown in open ponds or closed bioreactors. After harvesting, the oil is obtained and converted into biodiesel through transesterification. This biodiesel can be used in diesel engines without modification. The cultivation process involves strain selection, cultivation, harvesting, lipid extraction, and purification **[8].** Microalgae offer a sustainable, renewable biodiesel source and can grow in diverse environments such as freshwater, saltwater, and even wastewater.

3.1.1 Pentanol

Pentanol ($C_5H_{11}OH$), also known as amyl alcohol, is a colorless liquid with a distinctive odor. While it's used in solvents and fragrance production, it is less suitable for diesel engines due to its low cetane number, which results in poor ignition and increased emissions.

3.1.2 Di methyl carbonate

DMC is an oxygen-rich, low-toxicity compound studied as a diesel additive. It enhances combustion efficiency and reduces emissions of particulate matter, CO, and hydrocarbons. DMC’s higher cetane number and better compatibility with diesel fuel make it a safer and more effective oxygenate compared to alternatives like ethanol.

3.2 Process and Extraction of Oils

Several methods are used to extract lipids from microalgae for biodiesel production, including solvent extraction, microwave-assisted extraction, ultrasound-assisted extraction, and enzymatic hydrolysis.

3.2.1 Transesterification process

Transesterification involves reacting triglycerides (fats/oils) with alcohol to produce esters (biodiesel) and glycerol. Triglycerides consist of a glycerol backbone with three fatty acid chains, which influence the biodiesel’s properties. During the process, a catalyst—typically sodium or potassium hydroxide—facilitates the reaction between alcohol and the fatty acids, forming mono-alkyl esters and crude glycerol. Methanol or ethanol is commonly used; methanol yields methyl esters, while ethanol produces ethyl esters. Potassium hydroxide is more effective for ethyl esters, though either base works for methyl esters **[9,10].** A typical product from this process is Oil Methyl Ester (OME), formed when raw oil reacts with methanol.

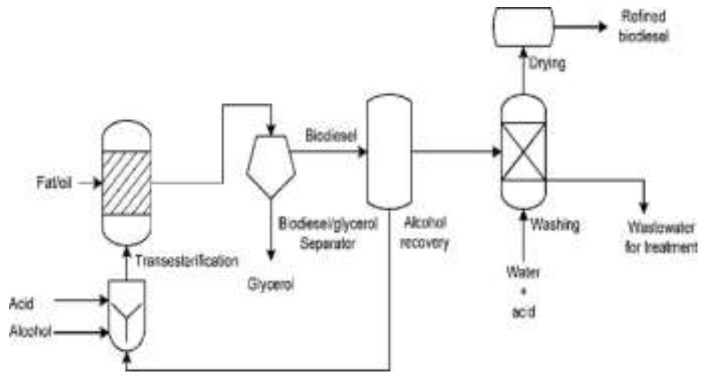


Fig.1 Transesterification process

3.2.2 Ultrasonication

Ultrasonication is an effective method for preparing nanoemulsions with controlled characteristics. In this experiment, 20 ppm of cerium oxide nanoparticles were added to a B20 biodiesel blend using an ultrasonicator. Ultrasound waves cause cavitation—formation, growth, and collapse of microbubbles—which creates localized high-energy zones. This intense environment facilitates physical changes, aiding emulsification. Emulsification occurs through initial droplet formation in the acoustic field and further dispersion via turbulence and microjets during cavity collapse, resulting in smaller, more stable droplets. Ultrasonication allows precise control over droplet size and enhances emulsion stability. The process alternates high- and low-pressure waves, causing vacuum bubble collapse in the liquid **[11,12].** This method can yield over 99% biodiesel and significantly shorten processing time—from 1–5 hours to under 5 minutes. It also reduces separation time from 5–10 hours (with conventional mixing) to less than 30 minutes.

IV. ENGINE SETUP

The setup features a single-cylinder, four-stroke diesel engine connected to an eddy current dynamometer for loading. It includes sensors for combustion pressure and crank-angle measurements, interfaced with a computer to generate PV diagrams. It also monitors airflow, fuel flow, temperatures, and load. A standalone panel houses components like an air box, fuel tank, manometer, fuel meter, transmitters, process and engine indicators. Rotameters measure cooling and calorimeter water flow.

4.1 Engine Specifications

TABLE.1 ENGINE SPECIFICATIONS

PARAMETERS	SPECIFICATIONS
Engine	Kirloskar TV1 Diesel Engine
Power	5.20kw
Speed	1500 rpm
No. Of cylinders	1(one)
Bore	87.50 mm
Stroke length	110 mm
Connecting rod length	234 mm
Compression ratio	17.5:1
Cooling medium	Water cooled

This setup supports performance analysis for parameters such as brake power, indicated power, frictional power, BMEP, IMEP, thermal efficiencies, mechanical and volumetric efficiency, specific fuel consumption, A/F ratio, and heat balance. LabVIEW-based "EngineSoft" software allows real-time performance monitoring. An optional computerized diesel injection pressure measurement is also available.

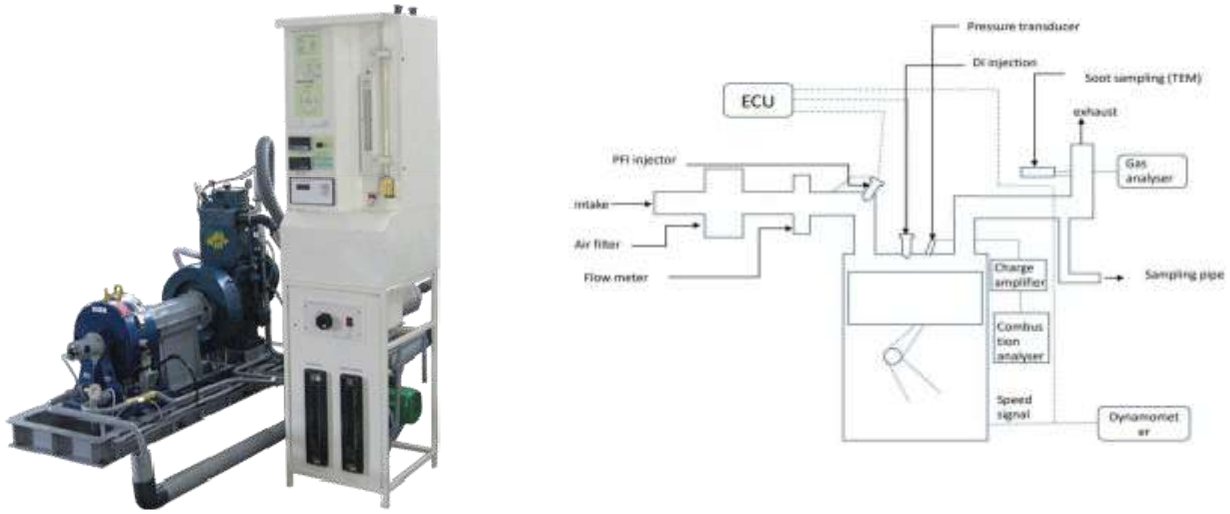


Fig.2 RCCI Engine setup & Block Diagram

4.2 Software

EngineSoft, developed by Apex Innovations Pvt. Ltd., is a LabVIEW-based engine monitoring system. It handles data entry, logging, analysis, and reporting. The software calculates power, efficiencies, fuel use, and heat release, and can be configured for different engine setups. It provides real-time data collection, graphical and tabular output, print options, and Excel export for further analysis.

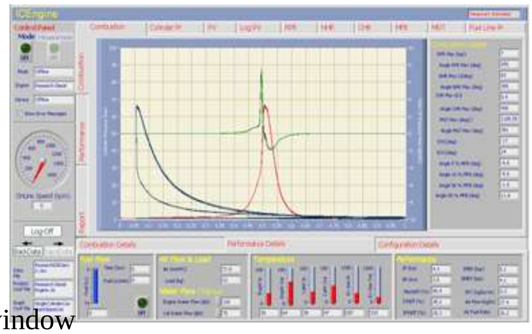
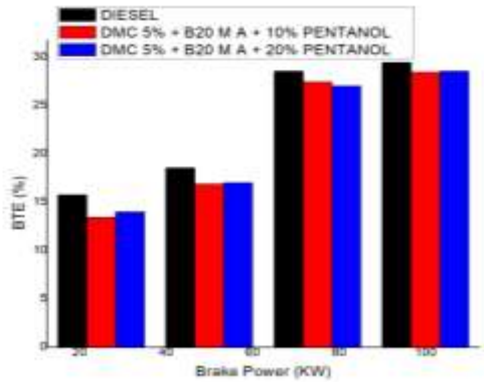


Fig.3 Smoke Analyzer Software window

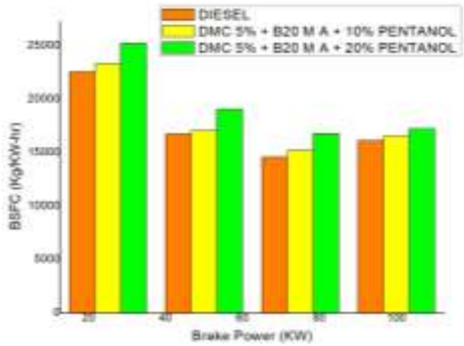
Fig. 4 Experimental setup

V. RESULTS AND DISCUSSION

5.1 Performance parameters



i. Brake Thermal Efficiency (BTE)



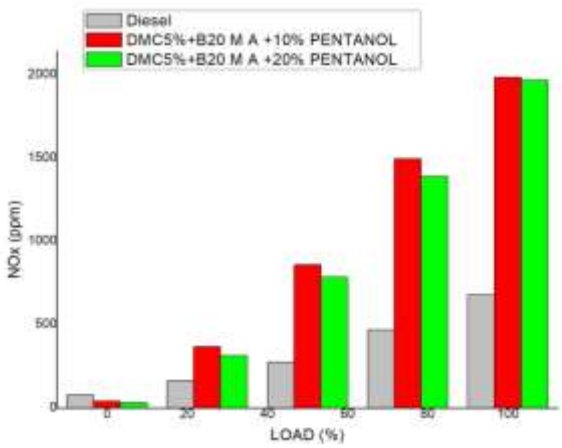
ii. Brake Specific Fuel Consumption (BSFC)

Fig.5 Graphs of Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC)

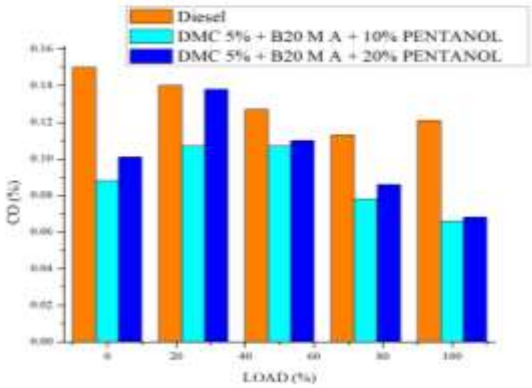
Brake Thermal Efficiency (BTE):
Fig. 5.i shows BTE variations across different blends and load conditions. BTE is the ratio of brake power to the fuel's energy input. Compared to diesel, both blends—DMC 5% + B20 M A + 10% Pentanol and DMC 5% + B20 M A + 20% Pentanol—show slightly lower BTE at all loads, with minimal variation.

Brake Specific Fuel Consumption (BSFC):
Fig. 5.ii compares BSFC of blends with diesel across load conditions. BSFC, the fuel consumed per unit of brake power per hour, is inversely related to BTE. Among all fuels, DMC 5% + B20 M A + 20% Pentanol showed the highest BSFC at all loads due to DMC's high oxygen content, which promotes complete combustion and increased fuel usage.

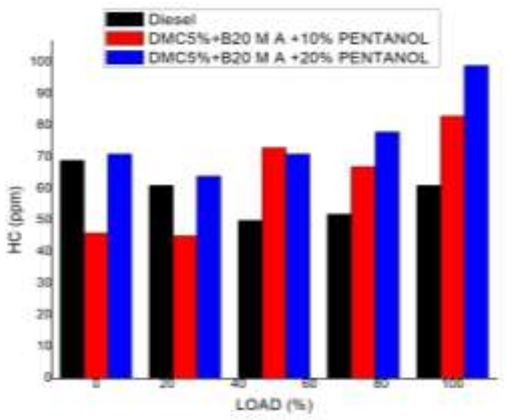
5.2 Emission Parameters



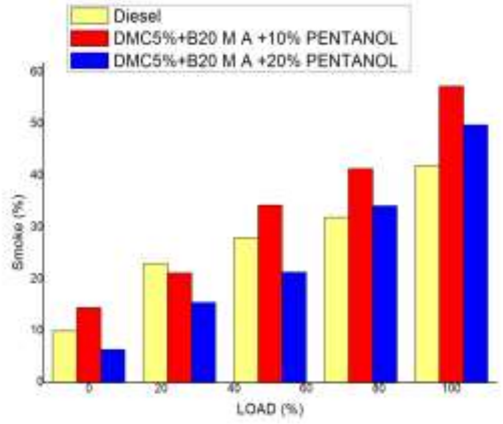
i. Oxides of Nitrogen (NOx)



ii. Carbon Monoxide (CO)



iii. Hydrocarbons (HC)



iv. Smoke Emissions

Fig.6 Graphs of NOx, CO, HC, Smoke emissions

Oxides of Nitrogen (NOx): NOx emissions were lowest at no load and increased with load. The blend DMC 5% + B20 M A + 20% Pentanol showed a 61.25% NOx reduction at no load compared to base fuel. Another blend, DMC 5% + B20 M A + 10% Pentanol, showed a 48.75% NOx reduction. This is due to the oxygen content in DMC enabling faster combustion, although higher nitrogen content in biofuels can raise NOx at higher loads.

Carbon Monoxide (CO): CO emissions, caused by incomplete combustion, were significantly lower in all test blends than in base diesel. This is attributed to the oxygen-rich DMC additive. At full load, the DMC 5% + B20 M A + 10% Pentanol blend reduced CO emissions by 45.45% compared to diesel.
Hydrocarbons (HC): HC emissions, another result of incomplete combustion, were lower at low loads for DMC 5% + B20 M A + 10% Pentanol—down 33.33% and 26.22% at 0% and 25% loads. Emissions increased with load, exceeding base fuel levels.

Smoke Emissions: Smoke was higher in base fuel up to half load. At 50% load, the DMC 5% + B20 M A + 20% Pentanol blend showed a 23.92% smoke reduction. This is due to DMC's high oxygen content and reduced blend density, enhancing combustion.

An initiative has been taken to develop solid, liquid, and gaseous biofuels as alternative energy sources. Current research focuses on third-generation biofuels from algal biomass, which overcome the drawbacks of earlier generations. Algae have been explored for cost-effective conversion into biodiesel, bioethanol, biogas, biohydrogen, and other valuable by-products. This review highlights recent advancements in algal biofuel production, emphasizing algal cell components, conversion strategies, and future potential for energy security.

VI. CONCLUSION

Experimentation was conducted with the diesel, micro algae bio diesel, Dimethtyl carbonate (DMC) and various volume percentage of Pentanol (10 and 20%). Readings were taken at various load conditions and the best conclusions are concluded below. When compared with the diesel, it is observed that the blend DMC 5% + B20 M A + 10% PENTANOL and DMC 5% + B20 M A + 20% PENTANOL possess lower BTE at all load conditions than conventional fuel. Among all the blends, the blend DMC 5% + B20 M A + 10% PENTANOL consumesfuel similar at all loads. It decreases with increase in engine load and it was found to be 2.62% increased BSFC when compared with the diesel. It is observed that high NOx emissions were observed in the blends DMC 5% + B20 M A + 10% PENTANOL and DMC 5% + B20 M A + 20% PENTANOL when compared with the diesel. The best blend is found to be DMC 5% + B20 M A + 20% PENTANOL which attained 61% less NOx emissions at no load condition. The CO emissions are reduced by 45% with the blend DMC

5% + B20 M A + 10% PENTANOL at FULL load when compared with the base fuel. The HC emissions are reduced by 33.33% with the blend DMC 5% + B20 M A + 10% PENTANOL at zero load when compared with the base fuel. The smoke emissions are reduced by 23.92% with the blend DMC 5% + B20 M A + 20% PENTANOL at half load when compared with the base fuel.

VII. REFERENCES

[1]. Verma, T., & Singh, M. (2024). *A study on biodiesel-fueled RCCI engine under varying load conditions*. Renewable Energy Advances, 11(1), 89–104. https://doi.org/10.1016/rea.2024.01.008

[2]. Kumar, S., Bansal, V., & Thakur, R. (2023). *Investigation of dual-fuel RCCI engine using biodiesel and natural gas: A performance perspective*. Energy Conversion and Management Reports, 7(4), 320–334. https://doi.org/10.1016/ecmr.2023.04.006

[3]. Patel, D., & Iqbal, M. (2024). *Comparative evaluation of biodiesel-RCCI engine with conventional diesel combustion*. Sustainable Engines and Fuel Systems Journal, 6(2), 172–185. https://doi.org/10.1016/sefsj.2024.02.009

[4]. C. Tiwari, G. Dwivedi, and T. N. Verma, "Experimental study of diesel engine performance and emissions from microalgae fuel blends with SiO_2 nanoadditives: RSM and Taguchi optimization," Environmental Science and Pollution Research, vol. 31, no. 12, pp. 12345–12356, Aug. 2024.Semantic Scholar, DOI: 10.1007/s11356-024-34724-6

[5]. Experimental Studies to Reduce Usage of Fossil Fuels and Improve Green Fuels by Adopting Hydrogen–Ammonia–Biodiesel as Trinary Fuel for RCCI Engine, Elumalai Ramachandran, Ravi Krishnaiah,ACS Omega 2024 9 (1), 741-752, DOI: 10.1021/acsomega.3c06327

[6]. Investigation on Ammonia–Biodiesel Fueled RCCI Combustion Engine Using a Split Injection Strategy, Elumalai Ramachandran, Ravi Krishnaiah, Elumalai Perumal Venkatesan, Chanduveetil Ahamed Saleel, and Saboor Shaik, ACS Omega 2023 8 (34), 30990-31001. DOI: 10.1021/acsomega.3c02641

[7]. Rolf D. Reitz, Ganesh Duraisamy, review of high efficiency and clean reactivity control compression ignition (RCCI) combustion in internal combustion engines, Engine Res. May, 2014.

[8]. Splitter D, Hanson R, Kokjohn S, et al. (2011) injection effects in low load RCCI dual fuel combustion. SAE Tech Pap.

[9]. Jia Z, Denbratt I (2015) experimental investigation of natural gas-diesel dual fuel RCCI in heavy-duty engine. SAE Int J Engines 8: 797-807.

[10]. Benajes J, Garcia A, Monsalve-Serrno J, et al. (2016) an assignment of dual mode reactivity controlled compression ignition in a EURO VI medium-duty diesel engine fueled with an intermediate ethanol-gasoline blend and bio diesel. Energy convers manage 123: 381-391.

[11]. Duraisamy G, Rangasamy N, Govindan N (2020) a comparative study on methanol/disesel and methanol/PODE dual-fuel RCCI combustion in an automotive diesel engine. Renewable energy 145: 542-556

[12]. Doosje E, Willems F, Baert R. experimental demonstration of RCCI in heavy- duty engines using diesel and natural gas. SAE Technical paper 2014-01-1318; 2014.