Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

An Empirical Investigation into the Comprehensive Efficiency and Emission Features of a Four-Stroke WCD-Rig Hydraulic Dynamometer Engine Utilizing a Blend of Octanol and Diesel Fuel

Sasmita Bal [a], Jayashree Nayak [b]*

[a] *Associate Professor, Mechanical Engineering, Alliance University, Bangalore, India*

[b]*Assistant Professor, Department of Mechanical Engineering, IGIT, Sarang, Odisha, India*

Abstract:- Growing concerns surrounding the exhaustion of non-renewable energy reservoirs and the ecological repercussions of engine exhaust discharges have ignited a quest for alternative fuels within the automotive industry. Alcohol-based fuels have surfaced as a promising alternative to traditional fossil fuels, particularly in water-cooled Diesel (WCD) engines. In the context of this empirical inquiry, a single-cylinder, water-cooled diesel engine was propelled by various blends of diesel and alcohol (10%, 20%, 30%, and 50% by volume). The incorporation of alcohol into the diesel blend yields a lighter fuel, contributing to improved combustion quality and a reduction in carbon emissions. The experimental arrangement integrates indispensable instruments such as a smoke meter and an emission analyzer to quantify opacity and collect exhaust gas data. The adoption of alcohol blends exhibits a significant reduction in nitrogen oxides, carbon monoxide, and unburned hydrocarbon emissions. Blends of octanol and diesel manifest lower in-cylinder pressure, pressure rise rate, and heat release rate. Furthermore, an increase in the compression ratio is identified as a factor that enhances combustion characteristics. The outcomes of this investigation offer valuable insights into the potential benefits of alcohol-diesel blends, underscoring their capacity to enhance combustion efficiency and mitigate the environmental impact of water-cooled Diesel engines.

Keywords: *Alternative fuels, Combustion quality, Exhaust gas analysis, Alcohol Fuel, Water cooled diesel engines*

1. Introduction

The global challenge of fossil fuel limitations and environmental degradation due to harmful emissions affects both industrial and transportation sectors, heavily reliant on diesel-powered vehicles. Diesel's compatibility with alternative fuels offers environmental and economic advantages, yet stringent regulations addressing internal combustion engine emissions are in place due to environmental concerns [1]. To tackle these challenges, academia and businesses actively research and implement alternative and renewable fuel solutions. Diesel engines, notorious for producing more soot particles and nitrogen oxides, face the demanding Euro VI emission standards, challenging with mere engine design modifications. In this context, higher alcohols like butanol, pentanol, hexanol, and octanol display potential [2-8]. Both Alcohol and Biodiesel can serve as alternative fuels for diesel engines, and adding alcohol, as tested globally, proves promising to reduce emissions without compromising engine efficiency [8-15].

Enhancing biodiesel performance and reducing exhaust emissions involves incorporating nanoparticles into biodiesel applications. Various nanoparticles, recognized for biodiesel additive capabilities, capture researchers' interest, prompting investigations into their thermo-physical characteristics, carbon emissions, fuel economy, combustion qualities, brake-thermal efficiency, and engine performance [16-19]. Utilizing alternative fuels is a viable strategy to mitigate carbon emissions [20-24]. Fossil fuel combustion releases carbon stored underground into the atmosphere, whereas biofuels release carbon sourced from crops, contributing to decarbonization and pollution reduction. Alternative fuels also demonstrate a capacity to reduce non-carbon emissions, including nitric oxide, nitrogen dioxide, Sulphur dioxide, and other harmful gases in exhaust [25-26], crucial in industries like mining where toxic gases can accumulate more easily. Supporters of alternative fuels argue for their cleaner, more environmentally friendly nature compared to fossil fuels, emphasizing potential cost savings, health benefits, reduced air pollution, and decreased reliance on foreign energy sources. Additionally, apprehensions are raised about the impact of some alternative fuels, manufactured with crops, on agriculture.

Octanol emerges as an optimal alternative to both gasoline and diesel engine fuels, boasting advantages such as a higher heating value, lower heat of vaporization, and production feasibility from various sources [27]. With superior thermophysical qualities compared to ethanol and methanol, higher viscosity, lower volatility, lower ignition temperature, and reduced corrosiveness, octanol stands out. Its production from renewable biomass enhances its appeal as a sustainable fuel, offering increased renewable percentages in fuel blends for improved energy security. Octanol's presence in alcohol fuel facilitates soot-free combustion. Long-chain alcohol, like octanol, proves more suitable for blending with diesel than short-chain alcohols due to higher energy content, stability, low corrosiveness, and lower miscibility in water. Heating values, flash point, and density closely align with diesel values [28-29]. Octanol isomers exhibit excellent solubility in diesel, simplifying blend preparation. The addition of octanol to diesel in blends enhances heat release rates, promotes combustion, and demonstrates excellent cold start performance. Incorporating exhaust gas recirculation (EGR) with Octanol-diesel blends achieves low-temperature combustion (LTC), reducing NOx and soot emissions with a slight impact on fuel economy [30-31].

Octanol, a colorless, slightly viscous liquid used as a defoaming or wetting agent, serves various industrial purposes. Its role as a solvent for protective coatings, waxes, oils, and a raw material for plasticizers underscores its versatility. Octanol, also known as octanol, is an organic compound with the molecular formula CH3(CH2)7OH. Many other isomers, generically known as octanols, exist. Octanol is manufactured for synthesizing esters used in perfumes. Esters of octanol, like octyl acetate, contribute to essential oils. Industrial production of octanol involves the oligomerization of ethylene using triethylaluminium, followed by oxidation of the alkyl aluminium products.

Engine performance and exhaust gas emissions are closely dependent on fuel properties, including density, viscosity, calorific value, cetane number, flash point, and pour point, among others. Simulation results [32] indicate a greater ignition delay when increasing the amount of n-octanol in biodiesel blends, attributed to the substantial latent heat of n-octanol vaporization lowering the starting combustion temperature. This aids in reducing hazardous NOx pollutant production. The increased oxygen concentration in n-octanol benefits power output and reduces soot emissions during combustion. Widely accepted among researchers, the fuel adulteration method [33] achieves specific fuel properties in the pursuit of enhancing the performance of a diesel engine and controlling emissions without the need for engine modifications. This study investigates combustion parameters, performance metrics, and emission characteristics through the variation of compression ratio, load, and ignition timing in a water-cooled diesel engine. The analysis of emission and performance features of a Water-cooled Diesel (WCD) engine encompasses the utilization of diesel and varying proportions of alcohol-blend fuels (10%, 20%, 30%, and 50% by volume).

This study investigates combustion parameters, performance metrics, and emission characteristics through the variation of compression ratio, load, and ignition timing in a water-cooled diesel engine. The analysis of emission and performance features of a Water-cooled Diesel (WCD) engine encompasses the utilization of diesel and varying proportions of alcohol-blend fuels (10%, 20%, 30%, and 50% by volume).

2. Materials and Method

2.1. Preparation of different blends of octanol and diesel

Diesel fuel, also called diesel oil or historically heavy oil, is any liquid fuel specifically designed for use in a diesel engine, a type of internal combustion engine in which fuel ignition takes place without a spark as a result of compression of the inlet air and then injection of fuel. Therefore, diesel fuel needs good compression ignition characteristics. For the analysis, diesel was purchased from the nearest petrol pump, and its properties are enumerated below. By using different ASTM methods, the various properties of diesel and octanol were determined and presented in Table 1.

Table 1: Properties of diesel and n-octanol

Fuel	***n*-Octanol**	**Diesel**
Oxygen content (wt.%)	12.31	0
Density (g/ml)	0.830	0.837
Heating value (MJ/kg)	38.4	42.8
Cetane number	37.5	52
Flash point (°C)	81	82
Viscosity @ 40 °C (mm^2/s)	5.5	3.04
Boiling point (°C)	195	193–357
Lubricity (μm)	236	315
Vaporization latent heat (kJ/kg)	562	270
Solubility in water	Immiscible	Immiscible

Based on 100% alternative, which contains 10% Octanol and 90% pure diesel is known as D90AO10(Diesel-Octanol). The total amount of D90AO10 tested was 400ml of which 10%-40 ml of Octanol and 90%-360 ml of neat diesel. The borosilicate beaker is placed on the magnetic stirrer, and then about 360 ml of diesel is measured with the help of the borosilicate beaker measuring level. Then 40 ml of Octanol was added with the help of a test tube (5ml capacity). The Teflon magnet was placed on the borosilicate beaker and the power was switched on. The Teflon magnet starts rotating and creating a vortex flow in the beaker, which is suitable. The power is supplied for up to 20-15 minutes to mix it properly and make a homogeneous mixture. The mixture was left after mixing for about 24 hours to check the stability and the mixture was found visually stable. In the same way, D80AO20, D70AO30, and D50AO50 were prepared. The process of creating the blend is illustrated in Figure 1.

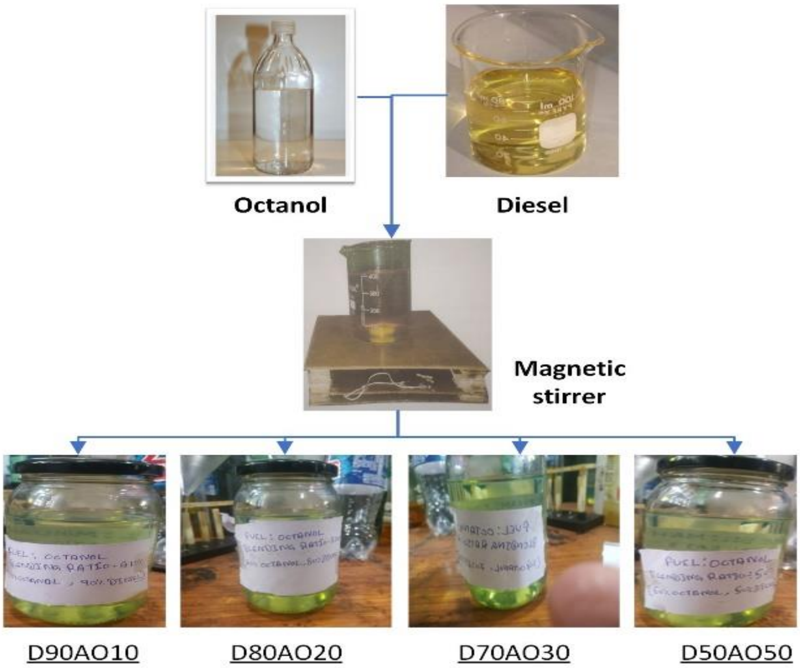

Figure 1: Making of Octanol-Diesel blending.

2.2. Determination of fuel properties

Before being used in diesel engines, the prepared blend of diesel and octanol must undergo testing to identify some of its properties, including calorific value, flash and fire point, viscosity, carbon residue, free fatty acid, pour point, cetane number, cloud point according to various ASTM methods. The properties are presented in Table 2.

Table 2: Blended fuel properties

Property	Diesel (D100)	Octanol (O100)	Diesel and Octanol (B10)	Diesel and Octanol (B20)	Diesel and Octanol (B30)	Diesel and Octanol (B50)
Density (Kg/m^3)	837	880.25	840.23	844.28	848.32	832
Viscosity (cst) at 40^{o}c	2.0549	8.713	2.954	3.8114	5.032	7.23
Flash point (^{o}C)	52^{0}C	89^{0}C	59^{0}C	65^{0}C	67^{0}C	77^{0}C
Fire point (^{0}C)	65	90	65	79	78	75

Calorific Value (MJ/Kg)	10241	9208	9972	9953	9918	9874
Cloud Point (°C)	18	15	13	11	12	10
Pour Point (°C)	-5	8	-7	-4	-6	-3

2.3. Experimental set-up

Figure 2 outlines the experimental setup for this study, utilizing a fixed 70 cc single-cylinder diesel engine designed for agricultural and low-power generation (see Table 3 for detailed specifications). The engine, connected to a hydraulic dynamometer with variable resistance load, was equipped with a spring balance weighing machine. An air surge tank with a U-tube manometer measured air consumption. A dual fuel supply setup included a T-type control valve regulating Diesel or Biodiesel. A 3-way control valve, connected to a Burette, measured the fuel consumption rate. A thermocouple on the exhaust pipe gauged exhaust gas temperature for combustion analysis. The experiment involved starting the engine and allowing it to stabilize for 15-20 minutes. The engine ran on various fuel blends, including diesel-Soybean biodiesel-ethanol, diesel-biodiesel-ethanol, diesel-Soybean biodiesel-isopropanol, diesel-Soybean biodiesel-ethanol-isopropanol, diesel-Soybean biodiesel-ethanol-isopropanol + alumina. Parameters like fuel and air consumption rates, exhaust gas temperature, and combustion characteristics were recorded at loads ranging from no load (0 kg, including flywheel) to full load (5 kg, including flywheel), with 20 minutes of operation at each load for stabilization. Efforts were made to maintain lubricating oil temperature below 90°C, and the experiment was repeated more than two times per load for reliability.

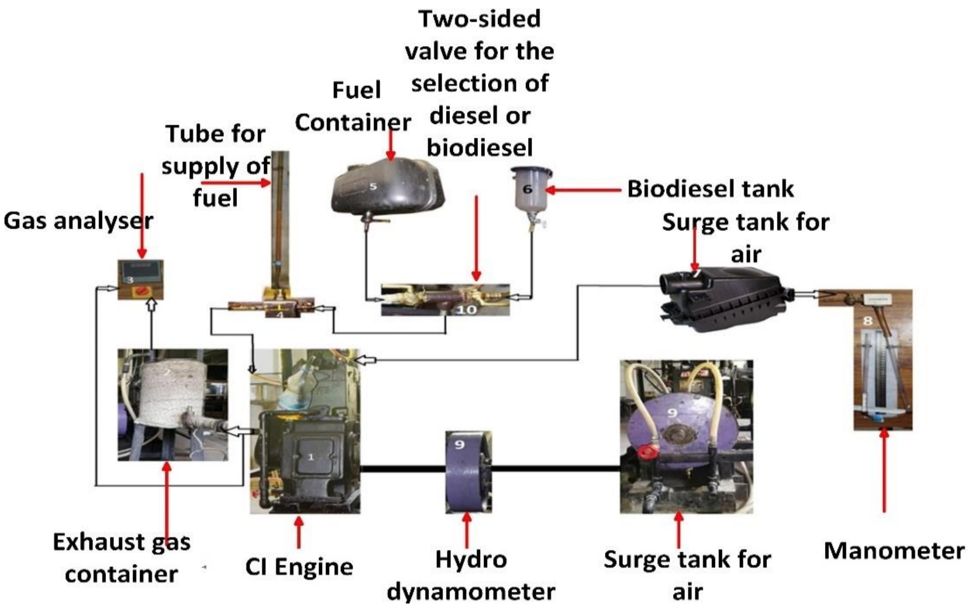

Figure 2: Schematic diagram of test apparatus.

Table 3: Technical data for Kirloskar 4-stroke Water cooled Diesel engine

Sr. No.	Technical Data	Value
1	Method of Cooling	Water
2	No. of Cylinder	1
3	Rated Power - B.H.P. / kW	3.5 / 2.6
4	Bore (mm)	80.0
5	Stroke (mm)	110.0
6	Rated R.P.M.	1500 TO 2200
7	Swept Volume (CC)	311
8	Compression Ratio	17.5:1
9	Method of Starting	Cold Starting with the help of Starting Handle
10	Engine Rotation	Standard Rotation Clockwise facing Flywheel
11	Fuel Tank Capacity (Lts.)	4.0
12	Sp. Fuel Consumption gms / bhp - hr	199
13	Sp. Fuel Consumption gms / Kwhr	270
14	Lubrication System	Plunger Pump
15	Lub. Oil Sump Capacity (Lts.)	1.000
16	Crank Shaft Height (mm)	140
17	Engine Net Weight (kg)	55
18	Engine Gross Weight (kg)	70

3. Results and Discussion

3.1 Combustion Performance of diesel by varying load and Injection rate

All experiments were conducted at the rated speed of 1500 rpm with compression ratio 18:1 and variable load conditions at room temperature. To minimize the uncertainty each test was repeated 5 times and the average value has been taken. All the readings were noted after achieving steady state condition and at stable exhaust gas, lubricating oil and water outlet temperatures. The engine was operated for around 30 minutes to stabilize and ensure that no previous fuel remained in the fuel supplying pipe in its new state before every fuel change. The previous fuel was removed from the fuel path and replaced with fresh diesel. After every test, the nozzles were cleaned and put back in place for the subsequent experiment. Every test was conducted with 210 bar of normal injection pressure and 10°, 15°, 20° BTDC injection advancement. Another important factor that primarily affects the combustion procedure and smoke generation is injection rate. The amount of gasoline pushed by the plunger in a unit of time is known as the injection rate. Fuel density affects the rate of fuel injection. Table 4 represents the variation of cumulative heat release rate in actual and predicted taken from the experimental set-up with crank angle.

Table 4: Variation of cumulative heat release rate in actual and predicted with crank angle.

Crank Angle(^{0})	Blend (%)	Load (Kg)	Injection Rate (mg/cycle/^{o}CA)	Cumulative heat release rate (CHRR) Actual in Watt	Cumulative heat release rate (CHRR) Predicted in Watt
220	10	0	-0.7	1.45	1.47
220.	10	3	0.6	1.34	1.35
220	10	6	0.5	1.55	1.56

300	20	0	-0.6	1.65	1.66
300	20	3	-0.4	1.55	1.56
300	20	6	-0.5	1.52	1.53
400	30	0	-0.4	1.55	1.57
400	30	3	-0.6	1.29	1.30
400	30	6	0.5	1.45	1.47

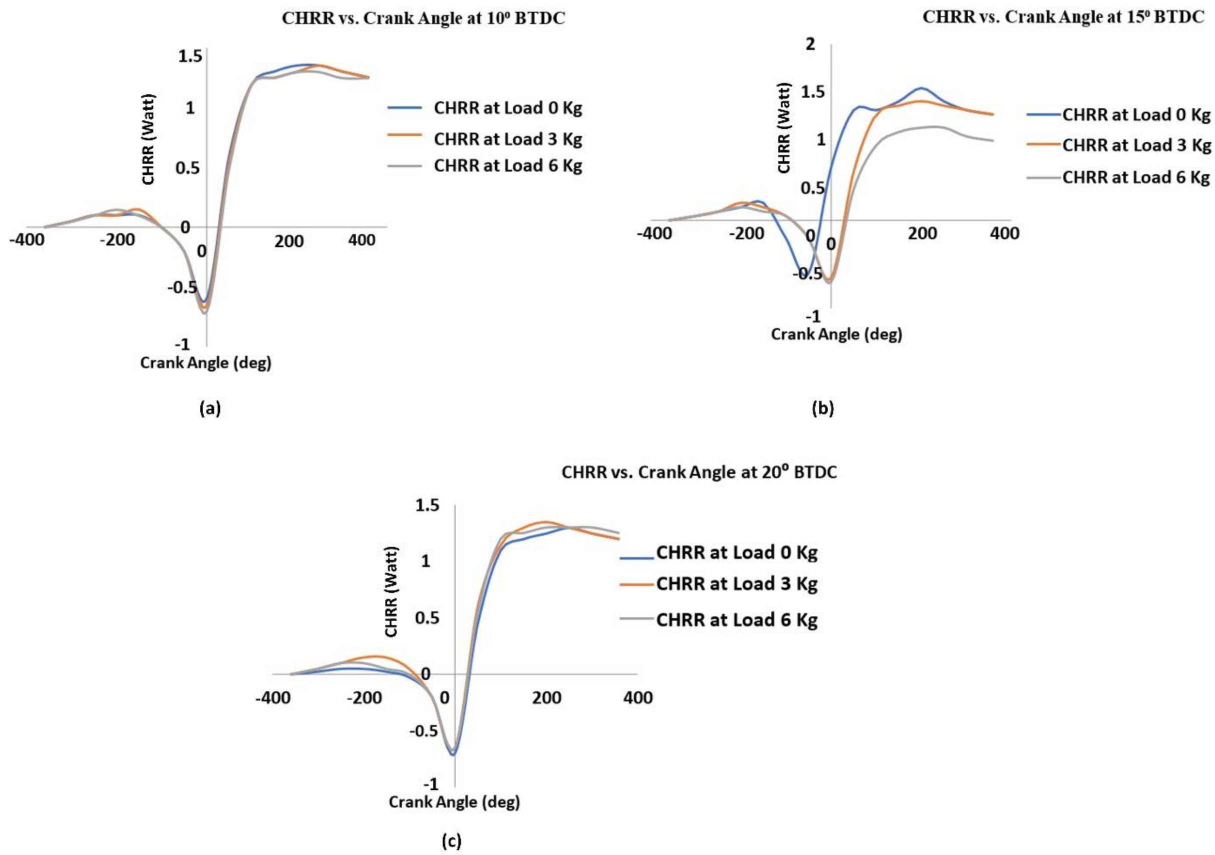

Figure 3: Variation of CHRR with Crank Angel.

The above three graphs shown in Figure 3 interpret the relationship between cumulative heat release rate (CHRR) vs. Crank angle for BTDC 10, 15, and 20 degrees, we found that as crank angle increases in the range of -360 to -10 degrees, there is a gradual decrease of CHRR for all the three loads. As the crank angle increases from -10 to 40 degrees, we observe that there is a sharp increase of CHRR in the range of -0.7 to 1.4 for all three loads. Peak values were obtained for Load 0 Kg followed by load 3 Kg and least for load 6 Kg.

3.2. Emission performance of WCD diesel engine for B50 blend

The exhaust emissions of diesel engine were evaluated by the measurement of HC, O_2, CO, CO_2, NO_X. The unburned hydrocarbon (HC) emissions for B50 alcohol/diesel blends under various tested circumstances are shown in Figure 4. The intensity of unburnt hydrocarbons found to be higher at full load compared to part load. This is because of the reach mixture. From the graph it was concluded that in 10° and 20° BTDC injection timing HC increases with increase in load but in 15° BTDC injection timing HC level gradually decrease with increase in load. This is explained by the fact that a longer ignition delay, a shorter burning time, and a delayed combustion results in higher HC value.

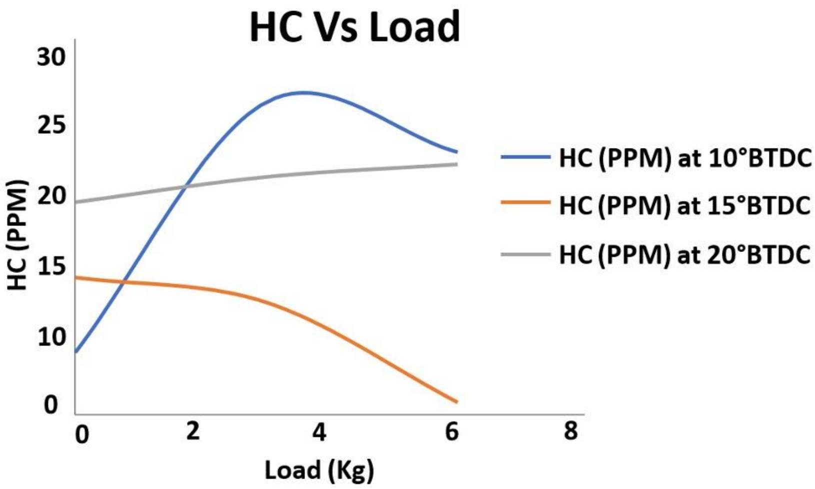

Figure 4: Variation of HC with Load for test fuels.

From figure 5, it is evident that in 10° & 20° BTDC injection timing O_2 decreases with increase in load but in 15° BTDC injection timing O_2 level gradually increases with increase in load.

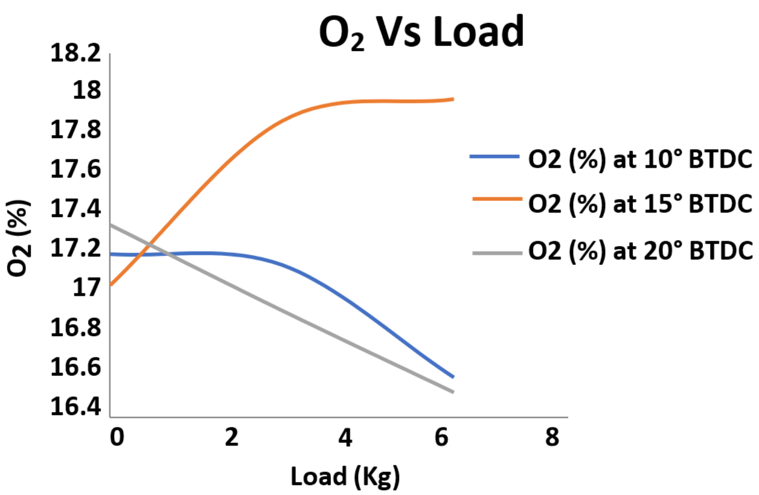

Figure 5: Variation of O_2 with Load for test fuels.

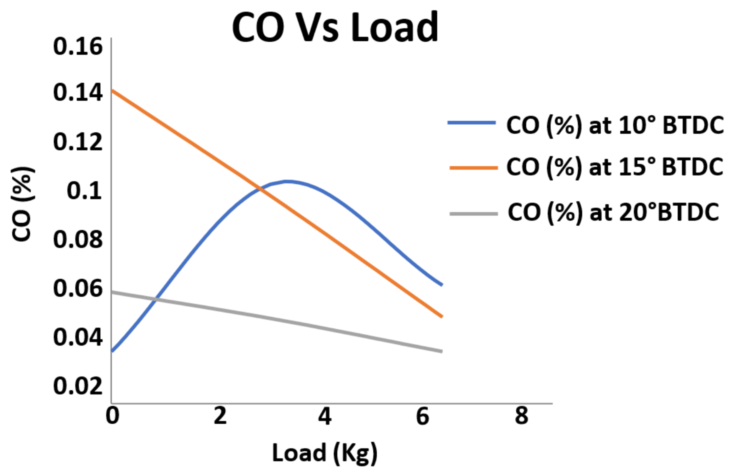

Figure 6: Variation of CO with Load for test fuels.

Variation of Carbon monoxide emissions with respect to load for B50 was graphically represented in Figure 6. The emission of CO is due to the incomplete combustion of hydro-carbon fuel. From the graph it was concluded that in 10° BTDC injection timing CO gradually increase & in higher load CO decrease but in 15° and 20° BTDC injection timing CO level gradually decease with load.

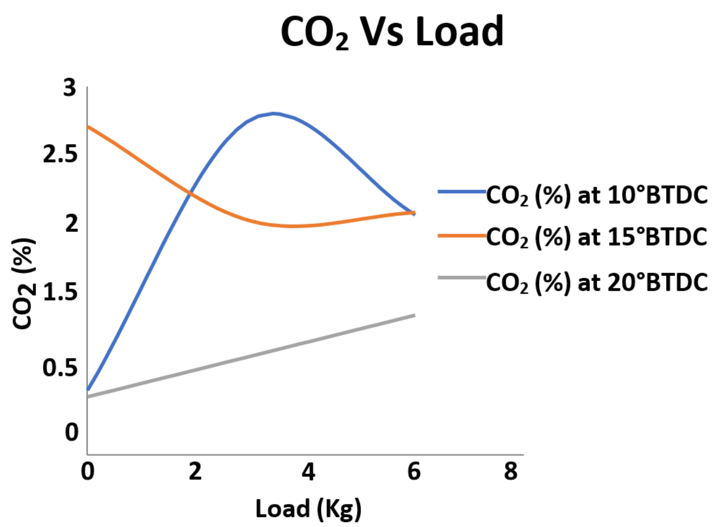

Figure 7: Variation of CO_2 with Load for test fuels.

In the above figure 7, it is evident that in 10° BTDC injection timing CO_2 first increases and then decreases with increase in load. The presence of carbon monoxide emission in engine exhaust is due to improper mixing and lack of sufficient oxygen for burning. Incomplete combustion of carbon based fuels are the main cause for this emission. At 15° BTDC injection timing CO_2 level gradually decrease first & then increase with increase in load. In 20° BTDC injection timing CO_2 increases with increase in load.

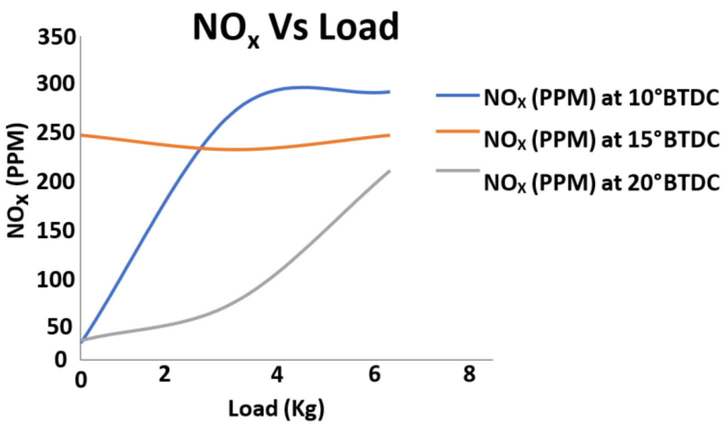

Figure 8: Variation of NO_x with Load for test fuels.

In Figure 8, we concluded that in 10° BTDC injection timing NOx first increases & then slight decrease with increase in load. 15° BTDC injection timing NOx level gradually decrease first & then increase with increase in load. In 20° BTDC injection timing NOx increases with increase in load.

K factor is the ratio of piston bowl volume to the clearance volume. This represents the amount of air available for combustion. Decrease in K factor indicates deterioration of combustion quality. With increase in load K_{avg} found to increase for 10°, 15°, 20° BTDC injection timing.

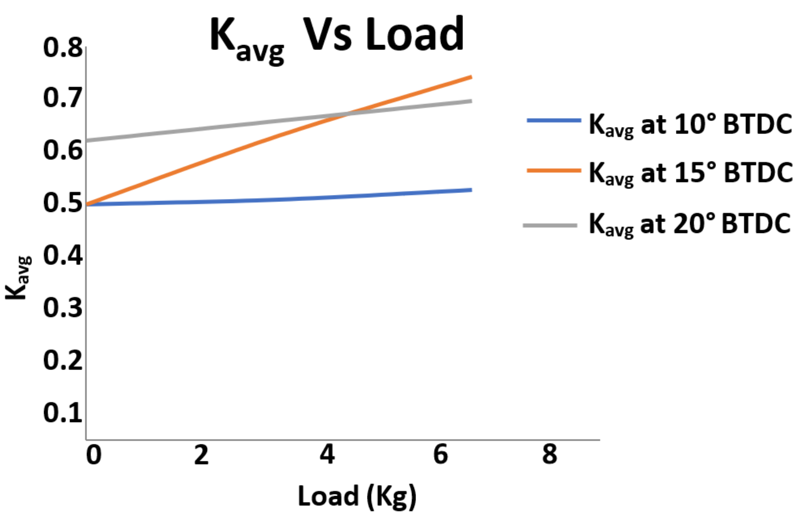

Figure 9: Variation of K_{avg} with Load for test fuels.

4. Conclusion

In conclusion, changing the compression ratio and load has nearly identical effects on engines running on diesel, diesel blends, and blends of diesel and octanol. Brake thermal efficiency is increased by increasing the compression ratio and load to a certain point, which also reduces the amount of fuel specifically used for the brakes and the emissions of CO, HC, and O2. Changes in other parameters, such as injection pressure and time, may also affect the outcomes. The temperature of the exhaust gas rises as the compression ratio rises. It is found that there is a significant increase in Net Heat Release for crank angle in the range, followed by a quick decrease for the same parameter. Changes in other parameters, such as injection pressure and time, may also affect the outcomes. After a detailed combustion, performance and emission study on diesel engine, it is further suggested that to get optimal results optimization using different techniques can be further performed.

Refrences

[1] Gałuszka, A., Migaszewski, Z., & Namieśnik, J. (2013). The 12 principles of green analytical chemistry and the SIGNIFICANCE mnemonic of green analytical practices. TrAC Trends in Analytical Chemistry, 50, 78-84.

[2] Atmanli, A., & Yilmaz, N. (2020). An experimental assessment on semi-low temperature combustion using waste oil biodiesel/C3-C5 alcohol blends in a diesel engine. Fuel, 260, 116357.

[3] Yesilyurt, M. K., Eryilmaz, T., & Arslan, M. (2018). A comparative analysis of the engine performance, exhaust emissions and combustion behaviors of a compression ignition engine fuelled with biodiesel/diesel/1-butanol (C4 alcohol) and biodiesel/diesel/n-pentanol (C5 alcohol) fuel blends. Energy, 165, 1332-1351.

[4] Emiroğlu, A. O., & Şen, M. (2018). Combustion, performance and emission characteristics of various alcohol blends in a single cylinder diesel engine. Fuel, 212, 34-40.

[5] Nayyar, A., Sharma, D., Soni, S. L., & Mathur, A. (2017). Characterization of n-butanol diesel blends on a small size variable compression ratio diesel engine: Modeling and experimental investigation. Energy conversion and management, 150, 242-258.

[6] Iacono, G. E., Gurgacz, F., Bassegio, D., de Souza, S. N., & Secco, D. (2024). AGRICULTURAL TRACTOR ENGINE PERFORMANCE AND EMISSIONS USING BIODIESEL-ETHANOL BLENDS. Engenharia Agrícola, 44, e20230089.

[7] Thokchom, S. S. (2024). Numerically comparative assessment of different biodiesel & its blends on performance, combustion and emission characteristics. Industrial Crops and Products, 209, 117900.

[8] Cao, J., Liu, Q., Li, W., Yan, F., Zhong, W., Xuan, T., ... & Wang, Q. (2024). Experimental study of the effect of hydrogenated catalytic biodiesel-Ethanol blends on combustion and soot formation process within an optical engine. Thermal Science and Engineering Progress, 102445.

[9] Doğan, B., Ghanati, S. G., Yeşilyurt, M. K., & Yaman, H. (2024). Effects of compression ratio on the performance and emission levels of a CI engine fueled with safflower oil methyl ester through an engine simulation approach. Science and Technology for Energy Transition, 79, 16.

[10] López-Lorente, Á. I., Pena-Pereira, F., Pedersen-Bjergaard, S., Zuin, V. G., Ozkan, S. A., & Psillakis, E. (2022). The ten principles of green sample preparation. TrAC Trends in Analytical Chemistry, 148, 116530.

[11] Mafra, G., García-Valverde, M. T., Millán-Santiago, J., Carasek, E., Lucena, R., & Cárdenas, S. (2019). Returning to nature for the design of sorptive phases in solid-phase microextraction. Separations, 7(1), 2.

[12] Benedé, J. L., Chisvert, A., Lucena, R., & Cárdenas, S. (2021). A paper-based polystyrene/nylon Janus platform for the microextraction of UV filters in water samples as proof-of-concept. Microchimica Acta, 188, 1-12.

[13] Miao, Y., Kreider, P., Pommerenck, J., AuYeung, N. J., von Jouanne, A., Jovanovic, G., & Yokochi, A. (2022). CO2 reduction by multiple low-energy electric discharges in a microstructured reactor: experiments and modeling. Industrial & Engineering Chemistry Research, 61(30), 10756-10765.

[14] Rajagopalan, P., Andamon, M. M., & Woo, J. (2022). Year long monitoring of indoor air quality and ventilation in school classrooms in Victoria, Australia. Architectural Science Review, 65(1), 1-13.

[15] Yun, J., & Jeong, S. (2021). Contributions of economic growth, terrestrial sinks, and atmospheric transport to the increasing atmospheric CO 2 concentrations over the Korean Peninsula. Carbon Balance and Management, 16, 1-11.

[16] Qiao, N., & Wang, L. (2022). Satellite observed vegetation dynamics and drivers in the Namib sand sea over the recent 20 years. Ecohydrology, 15(3), e2420.

[17] Qiao, N., & Wang, L. (2022). Satellite observed vegetation dynamics and drivers in the Namib sand sea over the recent 20 years. Ecohydrology, 15(3), e2420.

[18] Gomez-Gener, L., Rocher-Ros, G., Battin, T., Cohen, M. J., Dalmagro, H. J., Dinsmore, K. J., ... & Sponseller, R. A. (2021). Global carbon dioxide efflux from rivers enhanced by high nocturnal emissions. Nature Geoscience, 14(5), 289-294.

[19] Ramesh, K., & Sridharan, S. (2018). Long-Term Trends in Tropical (10° N–15° N) Middle Atmosphere (40–110 km) CO2 Cooling. Journal of Geophysical Research: Space Physics, 123(7), 5661-5673.

[20] Tan, C. H., Ong, M. Y., Nomanbhay, S. M., Shamsuddin, A. H., & Show, P. L. (2021). The influence of COVID-19 on global CO2 emissions and climate change: A perspective from Malaysia. Sustainability, 13(15), 8461.

[21] Zhao, S., Zhang, J., Deng, Y., & Wang, N. (2021). Understanding the Increasing Hot Extremes over the Northern Extratropics Using Community Atmosphere Model. Asia-Pacific Journal of Atmospheric Sciences, 1-13.

[22] Popin, G. V., Santos, A. K., Oliveira, T. D. P., de Camargo, P. B., Cerri, C. E., & Siqueira-Neto, M. (2020). Sugarcane straw management for bioenergy: effects of global warming on greenhouse gas emissions and soil carbon storage. Mitigation and adaptation strategies for global change, 25, 559-577.

[23] Yadav, J., Venkatesh, P., & Pischinger, S. (2023). Application of micro-genetic algorithms to optimize piston bowl geometries for heavy-duty engines running on diesel and 1-Octanol fuels. Applied Thermal Engineering, 226, 120236.

[24] Li, J., Wan, T., Huang, H., Chen, G., Liang, J., & Lei, B. (2023). Prediction and Verification of Performance and Emission Characteristics of Diesel/Natural Gas Dual-Fuel Engine Based on Intelligent Algorithm. ACS omega, 8(20), 18212-18224.

[25] Estevez, R., Aguado-Deblas, L., López-Tenllado, F. J., Bautista, F. M., Romero, A. A., & Luna, D. (2024). Study on the Performance and Emissions of Triple Blends of Diesel/Waste Plastic Oil/Vegetable Oil in a Diesel Engine: Advancing Eco-Friendly Solutions. Energies, 17(6), 1322.

[26] Krishnamoorthi, T., Sampath, S., Saravanamuthu, M., Vengadesan, E., & Dillikannan, D. (2024). Combined influence of thermal barrier coating and nanoparticle on performance and emissions of DI diesel engine fueled with neat palm oil biodiesel: An Experimental, Statistical and Energy and Exergy Analysis. Process Safety and Environmental Protection.

[27] Rami Reddy, S., & Sarangi, S. K. (2024). Emission and performance investigation of mango seed oil biodiesel supplied with n-pentanol and n-hexanol additives and optimization of fuel blends using modified deep neural network. International Journal of Chemical Reactor Engineering, (0).

[28] Samanta, A., & Roy, P. C. (2023). Experimental and Theoretical Assessment of a Diesel Engine Using Different Palm Oil Methyl Ester (POME) Blends at Different Compression Ratios. Journal of The Institution of Engineers (India): Series C, 104(5), 1031-1046.

[29] Balakrishnan, N. K., Teoh, Y. H., How, H. G., Le, T. D., & Nguyen, H. T. (2023). An Experimental Investigation on the Characteristics of a Compression Ignition Engine Fuelled by Diesel-Palm Biodiesel–Ethanol/Propanol Based Ternary Blends. Energies, 16(2), 1003.

[30] Kumar, V., & Choudhary, A. K. (2023). A hybrid response surface methodology and multi-criteria decision making model to investigate the performance and emission characteristics of a diesel engine fueled with phenolic antioxidant additive and biodiesel blends. Journal of Energy Resources Technology, 145(9), 092302.

[31] Mishra, P. C., Deshpande, H. N., & Bhosale, S. Y. (2023). Influence of Mustard Oil Biodiesel Blends in Common Rail Direct Injection Diesel Engine on Its Performance and Emission Characteristics. Energy and Environment Focus, 7(2), 170-176.

[32] Leo, G. L., Murugapoopathi, S., Thodda, G., Baligidad, S. M., Jayabal, R., Nedunchezhiyan, M., & Devarajan, Y. (2023). Optimisation and environmental analysis of waste cashew nut shell oil biodiesel/cerium oxide nanoparticles blends and acetylene fumigation in agricultural diesel engine. Sustainable Energy Technologies and Assessments, 58, 103375.