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Experimental Investigation of C. I Engine with Fish oil Viodiesel and n-Butonal Blends

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Abstract

The majority of the energy we consume for daily needs often originates from fossil fuels. This source is nonrenewable and pollutes the atmospheric air. Many researchers are working on biodiesel to replace this fuel for better performance of the engine with reduced emissions. The primary goal of this research is to reduce pollution and to study performance of diesel engines, with fish oil biodiesel. Various properties like calorific value, density, kinematic viscosity, flash and fire point for fish oil and its blends with diesel are determined as per the standard test procedures. Experiments are conducted to study the performance, emission and combustion characteristics of a Computerized 4-stroke, single-cylinder vertical water-cooled diesel engine using fish oil biodiesel blends. We also used n-butanol as an additive for better performance. Different parameters studied here are performance characteristics like specific fuel consumption, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, combustion parameters like Cylinder pressure and net heat release, and emission parameters like NO_x, CO, CO_2, HC, O_2, smoke density. Experiments are conducted at different load and results are compared with pure diesel. During the study, we found that 20% biodiesel blend is optimal when compared with all other blends and pure diesel.

Keywords: *Biodiesel, Cylinder Pressure, Emissions, Fish Oil, Thermal Efficiency*

1.0 Introduction

More than 7 million diesel engines are employed in agricultural operations in India. Due to their simple and durable design, these engines are highly efficient, provide precise power output with the greatest fuel economy and longer life duration, and are extensively utilized in thermal power production, transportation, and many other industries. The global growth in the number of transportation vehicles has led to an increase in the consumption of fossil fuels, which in turn has exacerbated environmental pollution, causing climate change and acid rain. Emissions from exhaust gas of diesel engines have become serious problem for researchers. Diesel engines are the biggest source of Particulate Matter (PM), oxides of nitrogen (NO_x), carbon monoxide (CO), and other dangerous substances that pollute the air and cause serious health problems for people. In light of growing concerns about the impact of diesel engine particle and NOx emissions on human health and the environment, as well as stricter government regulations on exhaust emissions, lowering the NO_x and particulate emission from diesel engines is one of the greatest difficulties. A significant amount of research has been conducted in this area to create in-cylinder control strategies by altering the concentration of fuels to reduce NO_x emissions from the exhaust and formation in the cylinder, respectively. The fast depletion and unequal distribution of petroleum fuels, as well as their ever-increasing price and environmental concerns, prompted the hunt for a replacement fuel. Using oxygenated fuels either in pure form or combined with diesel to give adequate

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oxygen and enhance combustion, hence lowering PM emissions and perhaps NO_x emissions, is the greatest alternative solution for addressing this essential problem.

Oxygenated fuels include oxygenates, an alcohol additives designed to minimize carbon monoxide and soot emissions. Oxygen atoms are chemically bonded inside the fuel structure of oxygenated fuels. In oxygenated fuel, the oxygen bond is energetic, resulting in a chemical reaction that ensures no efficiency loss throughout the combustion process. In order to decrease particle and soot emissions, these fuels should either be used undiluted or mixed with diesel fuel. As they are incompatible with diesel fuel, butanol, methanol, and ethanol are extensively utilized oxygenated fuels in diesel engines. However, concentrations of these oxygenated fuels above 10% diminish engine power and increase Brake Specific Fuel Consumption (BSFC). Other oxygenated fuels have a greater heating value and cetane number, while n-butanol has a lower volatility and is less hydrophilic. Additionally, butanol is less polar than shorter alcohols, which facilitates its miscibility with diesel fuels. All of these similarities to diesel fuel make butanol an ideal addition for compression ignition engines.

Tamilalagan *et al.,*[1] conducted a study on CI engine with 10-30% microbial-derived biodiesel blended with diesel. They observed reduced hydrocarbon and carbon monoxide emissions with 20% biodiesel blend, while brake thermal efficiency was increased and brake specific fuel consumption was decreased with same blend. In their investigation, Murthy *et al.,*[2] utilized canola oil blends, and they discovered that 40% blends resulted in improved performance and emissions. Tejesh *et al.,*[3] conducted experiments with sesame and palm oil mixtures. This dual biodiesel was blended with up to 40% diesel. They found lower CO and HC emissions with 30% blends. Harsha *et al.,*[4] conducted experiments by adding nanoparticles in diesel-biodiesel blend. They observed improved performance and lower emissions with 20% blends. Mohanty *et al.,*[5] conducted experiments on a C.I engine at compression ratio of 17.5 and 19. They used waste cooking oil biodiesel blends and they concluded that 20% biodiesel blend showed better performance and emission characteristics. Tejesh *et al.,*[6] experimented by blending Palm and Castor dual biodiesel with diesel. They declared that best thermal efficiency was found with a 10% blend, and the overall level of emissions was found to be lowest with a 40% blend. Savariraj *et al.,*[7] studied performances, combustion, and exhaust emissions of a C.I engine using fish oil biodiesel blends. It was observed that the emissions from pure biodiesel were lower than the remaining blends. Sharma *et al,.*[8] studied engine attributes using fish oil biodiesel and concluded that thermal efficiency increases and specific fuel consumption decreases for 20% blend and emissions are reduced for the same blend compared to all other blends. Karthikeyan *et al.,*[9] did investigations on a diesel engine using methyl esters of jatropha oil and fish oil. It was observed that combustion and performance characteristics of fish oil methyl ester are on par with diesel and Jatropha oil methyl ester. This indicates that the fish oil methyl ester is a viable alternative fuel. Ramesha *et al.,*[10] studied performances, combustion and emission characteristics of fish oil biodiesel blended with diesel and declared that 20% of biodiesel blends shows increased thermal efficiency and decreased specific fuel consumption and low NOx emissions. Similar results were obtained with neem oil[11] and cottonseed oil biodiesel[12] blends, with reduced emission contents.

2.0 Methodology

The discarded organs, fins, eyes, and tails of marine fish can be used to extract marine fish oil. Pure fish oil causes the fuel injector in the combustion chamber to choke and become blocked when used in a compression ignition engine. This might be minimized through pyrolysis, transesterification, and thermal cracking, which reduce the viscosity of the oil. Among these three processes, only transesterification is prevalent. Different percentages were then used to make the blends, which are referred as B0, B10, B20, B30 and B100 where the percentage of biodiesel in the mix is indicated by the number. From the blends, B20 is identified as optimum blend and proportions of 5 and 10% butanol is added for further investigation of diesel engine. The objective of this work is to produce biodiesel from waste fish oil using the transesterification process and to research its fuel attributes. Additionally, diesel engine characteristics were examined without any modifications to the engine configuration.

2.1 Transesterification

Transesterification is the process of changing one ester into another. For example, in biodiesel, glyceride ester is changed into alkyl ester by adding methanol. The molecule of biodiesel is smaller and has less parts. Transesterification shortens the carbon length of fatty acid molecules in oil, making biodiesel less thick. This procedure requires 1 litre of fish oil, 300 ml of 100% methanol, and 1gm of KOH as the catalyst. The KOH-methanol solution is now being stirred in a flask, after 5 minutes place the flask with the KOH-methanol solution aside. Then, we must mix the aforementioned solution with 1 litre of unrefined fish oil for 30 minutes to bring it to balance. It is necessary to let this solution sit at room temperature for 24 hours. To separate the glycerin required quantity of water must be added to the solution above which will sink to the bottom due to its high viscosity while the biodiesel will float to the top. Refined biodiesel is produced as a result.

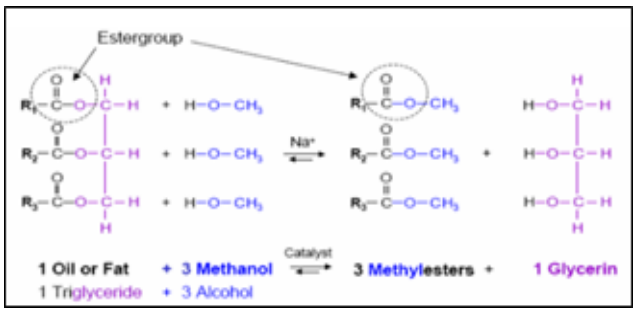


Figure 1. Mechanism of transesterification process.

2.2 Fuel Properties

We have measured the different properties of the biodiesel and its blends, and they are tabulated in Table 1.

3.0 Engine Setup

Experimental studies were carried out on a Kirloskar TV-1 single cylinder, direct injection, water cooled, four-stroke diesel engine. Figure 2 depicts the experimental setup. The engine power rating was 5.2 kW. An eddy current dynamometer was used to apply the engine load. Measuring air flow was accomplished by connecting the engine to a huge surge tank via an orifice meter. AVL



Figure 2. Schematic of engine setup.

Table 1. Properties of fuels

S.no	Blends	Density at 15^{0}c (kg/m^3)	Gross calorific value (kj/kg)	Kinematic viscosity (Mm^2/s)	Flashpoint (^{0}c)	Fire point(^{0}c)
1	DIESEL	830	42,500	3.07	56	63
2	B100	915	35,474	3.36	178	198
3	B10	838	41,797	3.16	72	75
4	B20	847	41,094	3.21	75	79
5	B30	855	40,392	3.26	80	83
6	B20BU5	845	40,670	3.17	73	77
7	B20BU10	843	40,245	3.14	71	75

shaft position encoder and an AVL GM12D tiny pressure transducer were utilised to measure crank angle and cylinder pressure respectively. Measurements of CO, HC, CO_2, O_2 and NO_x in exhaust gas were made using an AVL DI GAS 444N (Five gas analyzer), AVL 437C smoke meter was used to measure smoke density. Experiments were conducted from no load to full load with pure diesel and all blends (B10, B20, B30, B100) followed by B20BU5 and B20BU10 to further investigate the effect of n-butanol on the engine.

4.0 Results and Discussions

4.1 Performance Analysis

The various performance characteristics considered for the study are mean effective pressure, specific fuel consumption, mechanical efficiency, thermal efficiency and volumetric efficiency. The effects of load on the above parameters for different blends are discussed below.

4.1.1 Indicated Mean Effective Pressure

From the Figure 3 the IMEP of B20, B20BU5 and B30 at 100% are higher when compared to the remaining blends. The maximum IMEP obtained in 100% load condition for B20, B30 is 8.65bar, 8.71bar which is more than diesel (i.e. 8.44bar). At all load circumstances and for all mixes, the indicated mean effective pressure exceeded diesel levels.

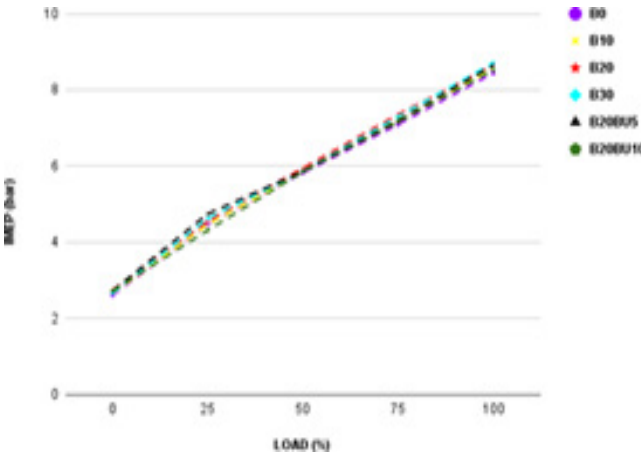


Figure 3. Variation of IMEP with load.

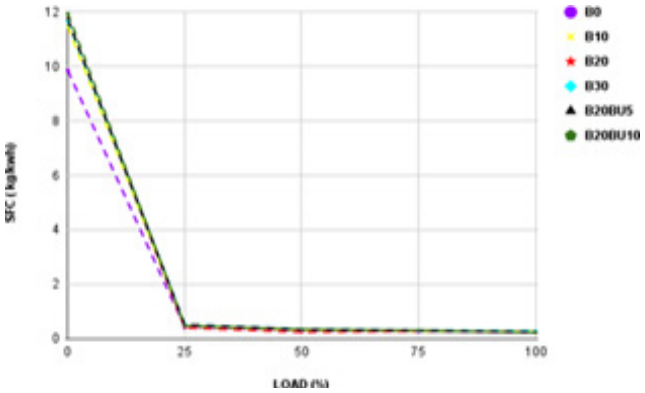


Figure 4. Variation of SFC with load.

4.1.2 Specific Fuel Consumption

Figure 4 depicts the specific fuel consumption of a motor for various mixes of fish oil biodiesel. At all loads, the

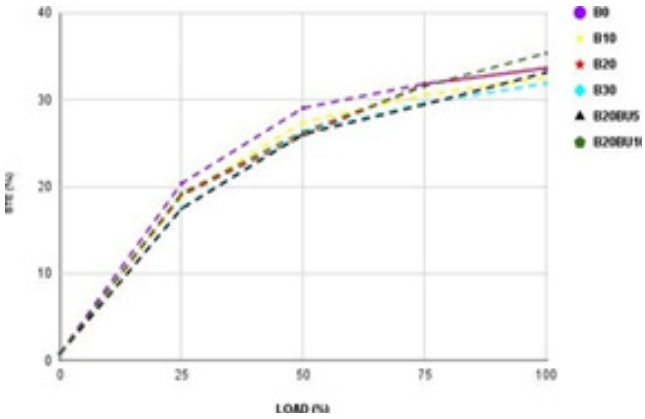


Figure 5. Variation of BTE with load.

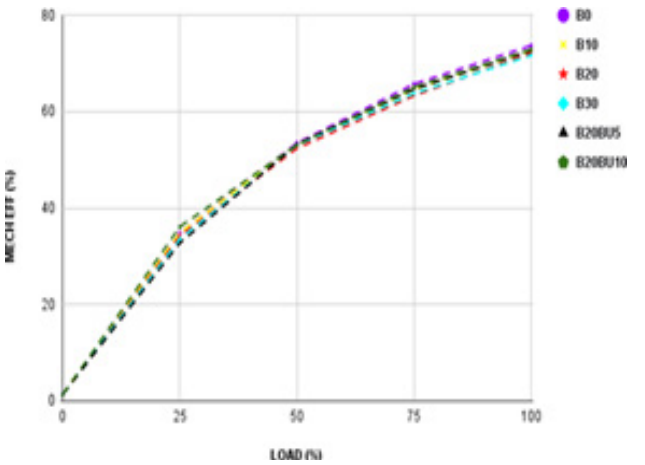


Figure 6. Variation of Mech efficiency with load.

SFC of B10 and B30 fuels is found to be almost identical to diesel fuel. However, the SFC for B20, B20BU5, and B20BU10 at 100% load was much lower than diesel fuel. Due to the larger area coverage of spray created inside combustion chamber by B20 blend and the efficient use of air, as well as the use of n-butanol as an additive, which further decreased SFC, B20BU10 had the lowest SFC when compared to all other blends and diesel fuel.

4.1.3 Brake Thermal Efficiency

Figure 5 for all fuels reveals that at 100% load, the blend B20 had a greater brake thermal efficiency than diesel fuel (i.e. for B20 and diesel, BTE values at 100% load are 34.54% and 33.59% respectively). BTE for B10 and B30 is somewhat less than diesel, however the graph demonstrates that there was no difference between these fuels at 0% load due to the low calorific value of all blends. The addition of 5 and 10% n-butanol to the B20 mixture enhanced the brake thermal efficiency relative to the B20 value (i.e. 33.12% and 35.34% for B20BU5 and B20BU10 at 100% load).

4.1.4 Mechanical Efficiency

The variation of mechanical efficiency concerning different blends at different loads showed that the highest mechanical efficiency for blend B20BU10 at 100% load was 72.92% which was slightly lower than diesel (i.e. 73.68% at 100% load). All blends at all loads gave diesel-like outcomes. For blend B20 mechanical efficiency at 100% load was 72.15% which is close to diesel (i.e. 73.68%).

4.2 Combustion Analysis

4.2.1 Cylinder Pressure

Figures (7-11) depicts fluctuation in cylinder pressure with crank angle for different blends of biodiesel at different loads. The injection pressure used is 200bar at an injection timing of 23^0 BTDC. It is evident from the graph (Figure 7) that, blends B20BU5 and B20BU10 showed a consistent rise in cylinder pressure at 0% load. At 25% load (Figure 8) B30 blend exhibited highest cylinder pressure rise. At 50% load, blends B20BU5 and B20BU10 show a steady increase in-cylinder pressure (Figure 9). Equivalently at 75% load B20BU10 showed

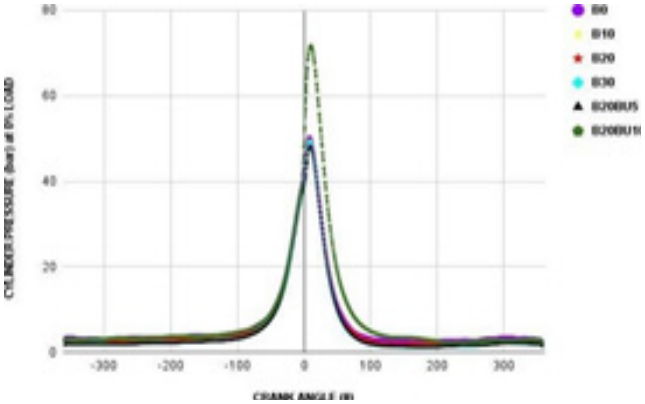


Figure 7. CP VS CA at 0% load.

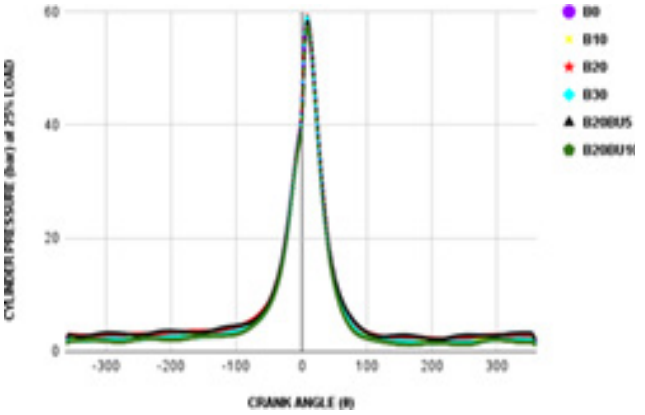


Figure 8. CP VS CA at 25% load.

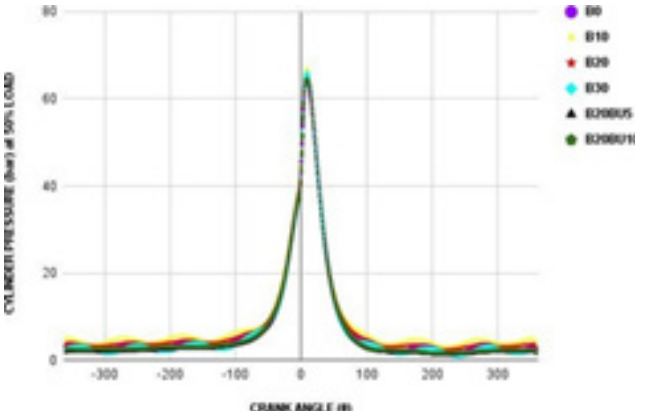


Figure 9. CP VS CA 50% load.

a maximum increase in-cylinder pressure (Figure 10). B20BU5, B20BU10 showed a higher cylinder pressure as compared to left-over blends at 100% load (Figure 11). Overall it can be concluded that blend

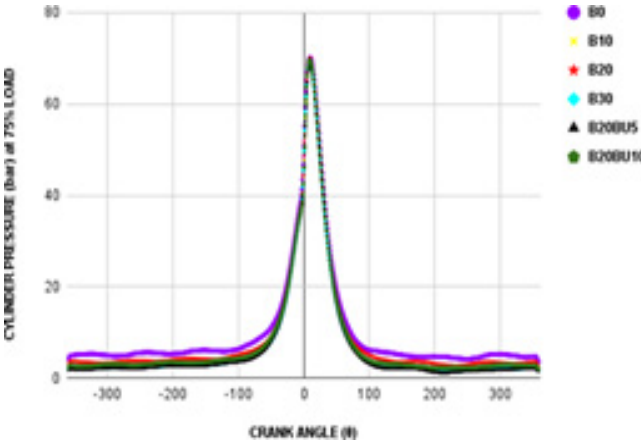


Figure 10. CP VS CA at 75% load.

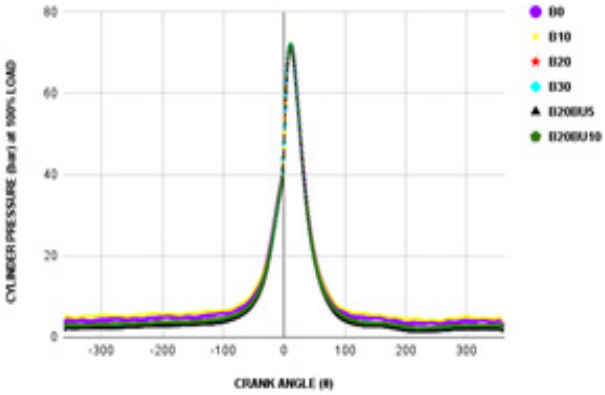


Figure 11. CP VS CA at 100% load.

B20 with the n-butanol additive added demonstrated the greatest pressure rise for B20BU5 and B20BU10, respectively.

4.2.2 Net Heat Release Rate

Figure 15 demonstrates that B20 has a maximum heat release of 49.66J/deg, which is 4.53% larger than diesel (45.13J/deg) at 75% load condition. The data also demonstrates that B10 and B30 mixes produce more heat than diesel. At partial loads, heat loss to the surrounding environment is greater than at 0 percent and 100 percent load. The net heat release is enhanced when n-butanol is added to B20 at concentrations of 5 and 10 percent. The highest heat release for blend B20BU10 at 75 percent load was 52.14J/deg, which is more than diesel. Blends

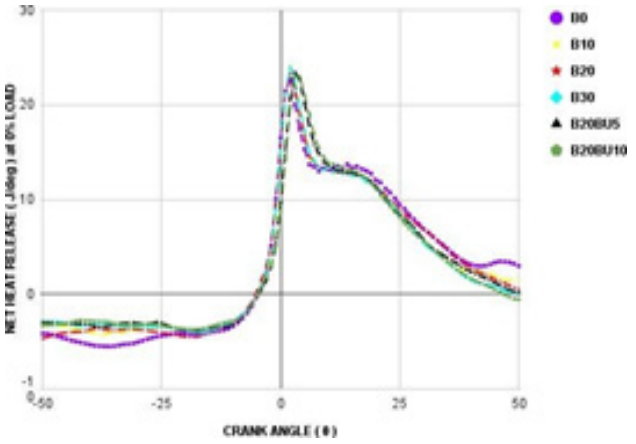


Figure 12. CP VS CA at 75% load.

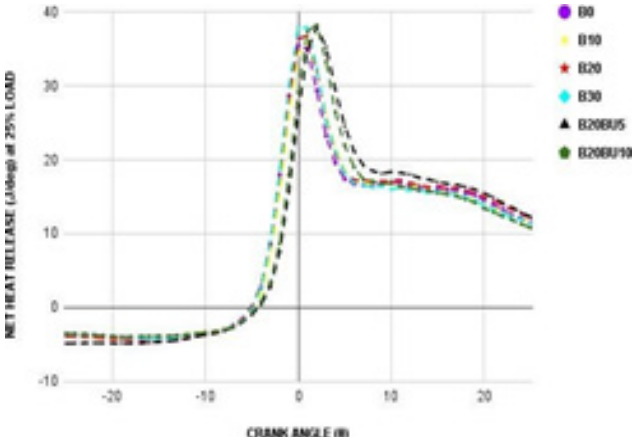


Figure 13. NHRR VS CA at 25% load.

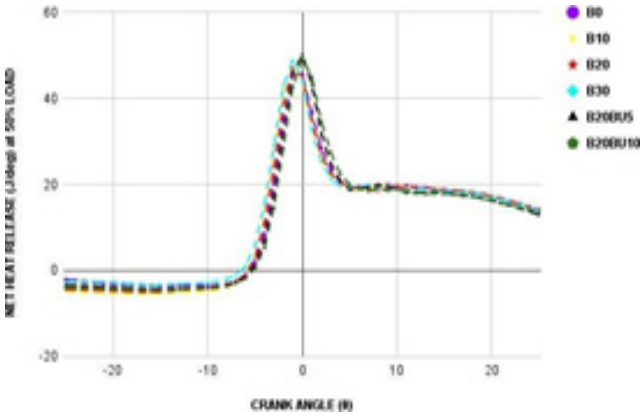


Figure 14. NHRR VS CA at 50% load.

B20BU5 and B20BU10 produce more heat than diesel under all loads.

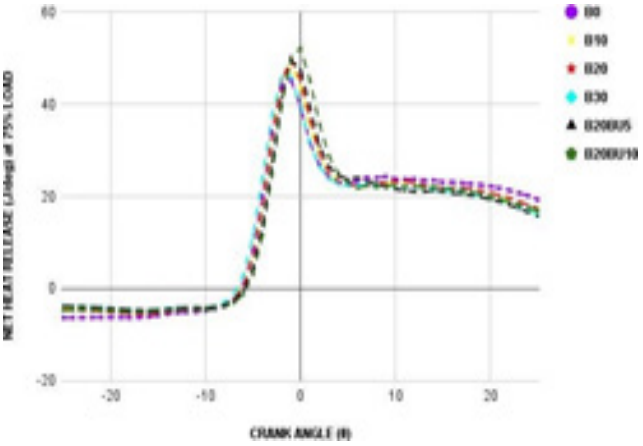


Figure 15. NHRR VS CA at 75% load.

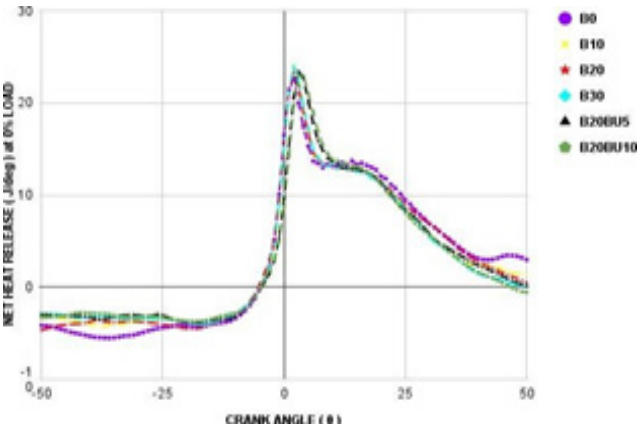


Figure 16. NHRR VS CA at 100% load.

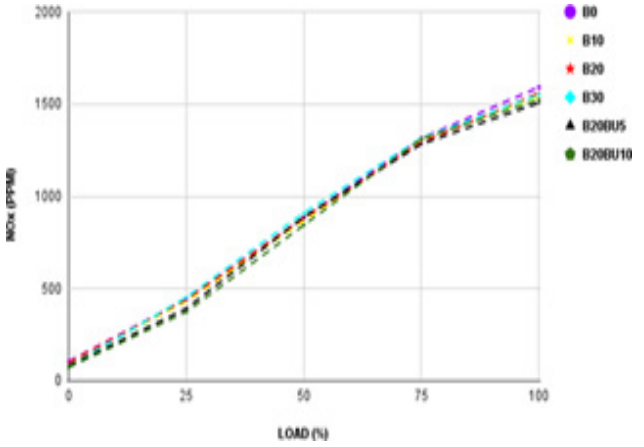


Figure 17. Comparison of the NOx emission patterns produced by diesel and biodiesel mixes.

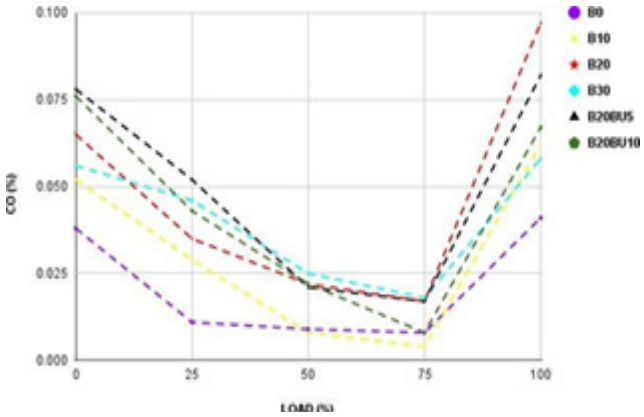


Figure 18. Comparison of the CO emission patterns produced by diesel and biodiesel mixes.

4.3 Emission Analysis

4.3.1 NO_x Emissions

The most significant characteristic of biodiesel and its blends emissions is NO_x. The most dangerous gaseous engine emission is NO_x, its reduction is what engine researchers and makers are always aiming for. All blends between 0 and 100% load had lower NO_x emissions than diesel. B20 had the greatest decrease in emissions at all weights. NO_x emissions were significantly reduced when B20 was blended with 5% and 10% n-butanol. As a result, at all loads, the NO_x emissions from B20BU5 and B20BU10 blends were significantly lower than those from diesel. This is due to the properties of n-butanol which helped in reducing NO_x emissions.

4.3.2 CO Emissions

Due to incomplete combustion, carbon monoxide forms in the combustion chamber. It is decreased by increasing the fuel's oxygen concentration. This is because that its latent heat of vaporization is somewhat greater than that of diesel; as a consequence, there is not enough vaporization and very little time for the fuel to burn entirely, resulting in a significant rise in CO emissions at higher loads. According to reports, CO emissions for biodiesel (i.e., for all mixes at all loads) are somewhat higher than those for diesel. CO emissions at 100 percent load for blends B20, B20BU5, B20BU10, B30, and Diesel are 0.097%, 0.082%, 0.067%, 0.058%, and 0.041% respectively.

4.3.3 CO_2 Emissions

When fuel is burned completely, CO_2 is produced. The main cause of global warming is CO_2. When compared to CO concentrations, the concentrations exhibit the reverse trend, which may be attributed to advancements in the combustion process. A rise in combustion temperature and oxidation rates are two more factors. The fuel's carbon-to-hydrogen ratio affects CO_2 generation. A hydrocarbon fuel should burn stoichiometrically to produce just CO_2 and water, depending on the fuel's carbon-to-hydrogen content. For all loads, CO_2 emissions rise with all blends (B10, B20, B30, B20BU5, B20BU10), and this is clearly shown in Figure 19.

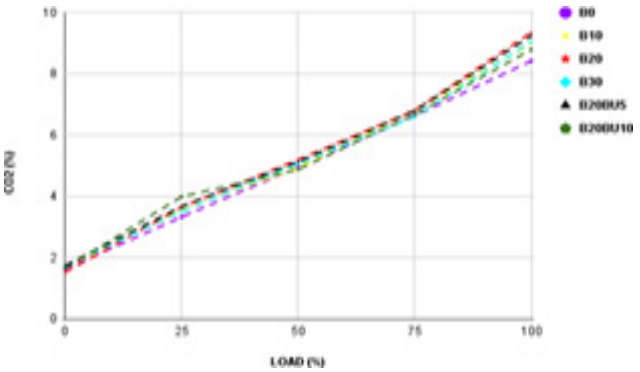


Figure 19. Comparison of the CO_2 emission patterns produced by diesel and biodiesel mixes.

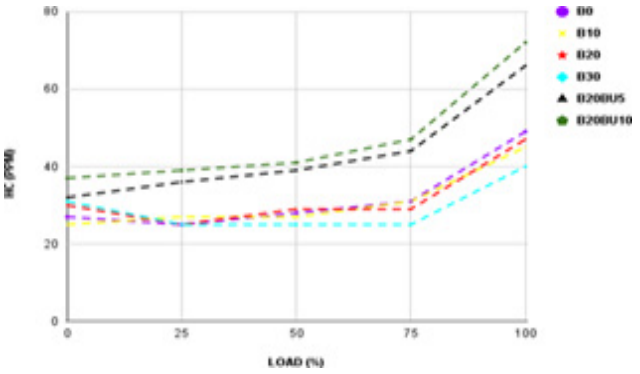


Figure 20. Comparison of the HC emission patterns produced by diesel and biodiesel mixes.

4.3.4 HC Emissions

Figure 20 depicts variation in HC emissions as a function of load. For all of the fish oil biodiesel blends, it has been shown that HC increases as load increases. At greater loads, the HC emissions from all blends were higher than those from diesel, compared to other blends and diesel, the HC emissions of B20BU5 and B20BU10 increase at full load.

4.3.5 Smoke Capacity

Smoke opacity is used to determine how much particulate matter is in exhaust gas. The change in smoke opacity with load for various biodiesel and diesel mixes is seen in Figure 21. B30's opacity at full load in this case is 59.1 percent, which is less than diesel's 62.9 percent. The addition of n-butanol (i.e. 5% and 10%) to B20 showed a significant reduction in smoke opacity for the blends B20BU5 and B20BU10 at all loads.

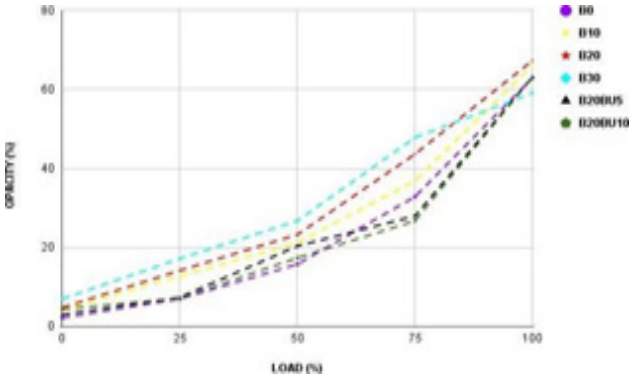


Figure 21. Comparison of the smoke opacity emission patterns produced by diesel and biodiesel mixes.

5.0 Conclusions

Fish oil biodiesel is experimentally investigated for performance improvement and NOx reduction using n-butanol as an additive to optimum blend (i.e. B20). The following conclusions have been obtained for fish oil biodiesel with and without n-butanol addition based on testing findings.

- The performance, combustion and emission data of fish oil blends (B10, B20, B30) showed better results compared with conventional diesel. Among them B20 at full load show 34.54% BTE while diesel at same condition show 33.59% BTE and similarly emissions are less for B20 compared with conventional diesel. Therefore, B20 is identified as optimum condition to yield better results.

- The optimum blend B20 is now added with n-butanol additive in proportions of 5% v/v and 10% v/v to further investigate performance, combustion and emission parameters on similar conditions. It is identified that on addition of n-butanol further improved the BTE and reduced NOx emissions to better extent compared with B20 blend.
- The brake thermal efficiency for B20BU5, B20BU10, and conventional diesel is 33.12%, 35.34%, and 33.59%, respectively, at full load. It shows that, compared to standard diesel, B20BU10 has a much higher brake thermal efficiency.
- In the combustion parameters, cylinder pressure for B20 with addition of n-butanol showed maximum pressure rise for both B20BU5 and B20BU10 and net heat release rate for B20 is 49.66J/deg which is more than diesel by 4.53% at 75% load condition.
- In emission parameters, NO_x emissions reduced significantly for the blends compared with conventional diesel at all loads and with addition of n-butanol these were gradually reduced to a greater extent compared with optimum blend, good sign for reducing global pollution.
- Similarly, other emissions like CO, CO_2, HC, Smoke opacity increased slightly compared conventional diesel values at all loads take in experimentation.

It was therefore established that adding n-butanol to fish oil blend B20(i.e. B20BU10) at a proportion of 10% v/v produces the best results and can be used as a substitute for mineral diesel to increase brake thermal efficiency, reduce specific fuel consumption, and significantly reduce NOx emissions.

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