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EFFECT OF Al2O3 NANOPARTICLES ON PERFORMANCE AND EMISSION CHARACTERISTICS OF IC ENGINE FUELLED WITH DIESEL AND BIODIESEL BLENDS USING CHLORELLA ALGAE OIL

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Abstract:

The use of biodiesel, extracted from various sources and blended with engine fuels, addresses concerns such as fuel scarcity, pollution, and cost. Incorporating nano additives, like aluminum oxide (Al2O3), into algal oil Diesel-Biodiesel blends offers a method to mitigate emissions and enhance IC Engine performance. This study explores the utilization of chlorella algae oil as an alternative fuel, blended with diesel in varying proportions, with and without aluminum oxide as a nano additive. Blends, namely B20, B25, and B30, are tested in a CI diesel engine, and their properties are evaluated according to ASTM Standards. Experimental testing conducted on a single-cylinder four-stroke water-cooled diesel engine reveals that B20 exhibits superior results in terms of brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC), with lower emissions of hydrocarbons (HC) and carbon dioxide (CO2) compared to diesel. However, nitrogen oxide (NOX) and carbon monoxide (CO) emissions are marginally higher. Introducing aluminum oxide (Al2O3) nano additive to algae biodiesel (B20) at various proportions demonstrates improved thermal efficiency and lower NOX, HC, and CO2 emissions, approaching diesel levels. Nonetheless, CO emissions are slightly elevated. Comparative analysis of performance and emissions, including NOX, CO2, HC, and CO, is presented.
Keywords: Al2O3, biodiesel, chlorella algae, BSFC, NOx.

Introduction:

The importance of alternative fuels for diesel engines has escalated due to socioeconomic factors and heightened environmental concerns, particularly regarding global warming induced by greenhouse gas emissions. Biodiesel emerges as a viable alternative, derived from renewable biomass resources such as vegetable oils and animal fats, offering effective reduction of CO2 emissions. Biodiesel, produced via transesterification or etherification reactions, is renewable and biodegradable, making it environmentally friendly. Algae fuel, derived from microalgae, presents unique advantages, including minimal impact on fresh water resources, synthesis using ocean and wastewater, and biodegradability. Despite higher production costs, algal fuel exhibits promising potential, with certain algae species capable of converting up to 60% of their dry weight into oil. Research suggests algal fuel could play a significant role in meeting global diesel consumption demands, offering higher oil yields compared to conventional crops. Efficient production methods, utilizing high rate algal ponds or photo bioreactors, contribute to the feasibility of algal fuel as a sustainable energy source.

Literature Review:

Considerable research efforts have been devoted to the design and development of engines, aiming to improve performance and reduce emissions. Various approaches, including the use of different fuel blends, fuel injection timing adjustments, and the utilization of biodiesel with or without additives, have been explored extensively in this field. Aluminum oxide (Al2O3) emerges as a promising additive due to its favorable combustion characteristics.

Cheng Cheng et al. [1] investigated the influence of serial and parallel structures on two-phase flow behaviors in dual combustion chambers with a propelled body. Their findings emphasized the importance of understanding multi-dimensional flow and energy conversion behaviors, proposing a coupled approach to describe gas-solid flow with reaction in dual-chamber systems.

Varun et al. [2] examined modifications in combustion chamber geometry of CI engines to enhance suitability for biodiesel. Their study underscored the significant impact of combustion chamber geometry on engine performance and emissions, highlighting the need for meticulous consideration of these factors.

G. Najafi et al. [3] studied the effect of combustion management on diesel engine emissions fueled with biodiesel-diesel blends. Their findings emphasized the importance of employing multiple strategies simultaneously, such as combustion management, fuel additives, and after-treatment technology, to effectively reduce emissions. The study suggested that biofuels, including blends of diesel, biodiesel, and ethanol, offer a promising solution for emission reduction.

L.X. Sang et al. [4] investigated the modification of ternary carbonates with additives to improve thermal physical properties. Their study revealed the influence of additives on the melting point of ternary carbonates, suggesting potential enhancements in thermal properties through additive incorporation.

Md. Hasan Ali et al. [5] conducted experiments on biodiesel production from neem oil, emphasizing the importance of the transesterification process. Their study highlighted the potential of neem oil as a biodiesel feedstock and emphasized the need for continued optimization in biodiesel production processes.

Shruthi H et al. [6] focused on biodiesel production from crude neem oil and its performance characteristics. Their study highlighted the clean-burning nature of biodiesel produced from neem oil and its suitability as a fuel component for unmodified diesel engines.

Ahmed et al. [7] investigated the effect of Al2O3 nanoparticles on jojoba biodiesel-diesel blends, observing significant changes in fuel properties. Their study suggested a reduction in brake specific fuel consumption with the addition of Al2O3 nanoparticles, leading to reduced emissions.

Mohan Kumar et al. [8] conducted experimental investigations on the performance, combustion, and emission characteristics of DI diesel engines using algae as a biodiesel feedstock. Their study evaluated various algae-diesel blends, highlighting the potential of algae biodiesel as an alternative fuel.

S. Karthikeyan et al. [9] conducted experiments using Caulerpa racemose algae biofuel blended with Bi2O3 as a nano additive. Their study demonstrated improved performance and reduced emissions with the addition of Bi2O3 nano additives, suggesting its potential as a fuel enhancer.

Objective:

Numerous experiments have been conducted on CI engines using various types of vegetable oils, virgin feedstock, animal fats, multi-feedstock, and sewage sludge. Biodiesel fuels have shown potential as alternative fuels capable of reducing emissions of carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxide (NOx), and hydrocarbons (HC), while also improving the performance of internal combustion engines. This study focuses on using algae oil as a biodiesel, an alternative liquid fossil fuel. Algae, photosynthetic organisms related to plants, grow in water and utilize carbon dioxide and sunlight to produce energy. Single-celled microalgae can generate a significant amount of fat, which can be converted into biodiesel. In many experiments, biodiesel has been tested at different blend proportions, with B20, B25, and B30 identified as optimal blend ratios for this study. However, biodiesel fuels tend to emit higher NOx emissions.

Nano additives have emerged as promising options for reducing emissions and enhancing engine performance. Various types of nano additives, such as ethanol and methanol, have been studied. In this research, aluminum oxide is utilized as a nano additive. When used in IC engines, nanoparticles improve combustion characteristics, enhance atomization, sustain flames better, reduce brake specific fuel consumption (BSFC), and decrease NOx emissions. Optimal proportions of nano additives, specifically 80 ppm, 100 ppm, and 120 ppm, are considered for this study.

The objective of this experimental study is to evaluate the effect of aluminum oxide as a nano additive in algal oil blended with diesel in a single-cylinder diesel engine. This evaluation aims to assess both the performance and emissions characteristics using optimal blend ratios.

Methodology:

The methodology section outlines the step-by-step procedures and techniques employed to fulfill the objectives of the research project. Based on literature reviews, readings, and summaries conducted in the previous chapters, the following experimental tests will be carried out, encompassing four major tasks:

1. Preparation of biodiesel fuels (BDF) from algae-based sources and their mixtures with diesel fuel.
2. Execution of engine operations using various types and blending proportions of biodiesels as fuels, alongside standard diesel fuel (DSL).
3. Measurement of exhaust gas emissions released from the combustion of biofuels in a compression ignition (CI) diesel engine, including CO, CO2, HC, and NOx.

The overall research methodology or experimental flow will be presented in a simplified flow chart in the subsequent topic.

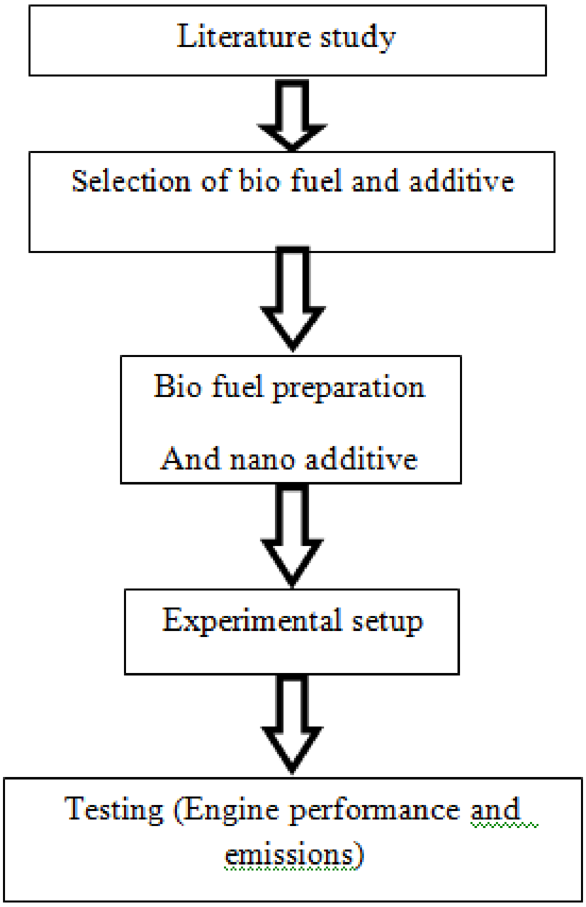

Fig : Flow chart of work

Materials Preparation:

In the first step of the study, Chlorella microalgae biofuel blends comprising 20%, 25%, and 30% are considered as fuels, with aluminum oxide (Al2O3) selected as the nano-additive to assess engine performance. In the second step, the engine is modified with optimized parameters. Finally, in the third step, the experimental results regarding emission characteristics of both the modified fuel and engine are compared with those of the existing baseline engine.

In the current study, Al2O3 nanoparticles are added in concentrations of 80 ppm (0.08 gm), 100 ppm (0.1 gm), and 120 ppm (0.12 gm) to one liter of 20% diary scum biodiesel. The nanoparticles are dispersed thoroughly within the biodiesel blend using an ultrasonicator and mechanical stirrer.

To prevent the sedimentation of nanoparticles, CTAB (Cetyl Trimethyl Ammonium Bromide) surfactant is employed to provide negative charge to the particles, thereby avoiding particle sedimentation. Before conducting experimentation, the fuel blends are thoroughly shaken to ensure proper dispersion of nanoparticles.

A schematic view of the preparation and utilization of nano-additive fuel blends is depicted in Figure 3.1, while Figure 3.2 illustrates the schematic view of the reactions between nanoparticles and fuel blends.

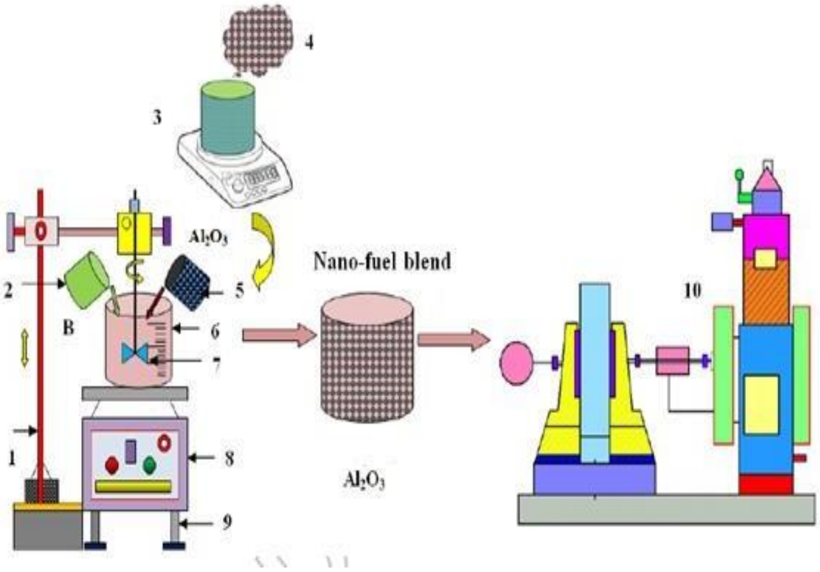

Figure 3.1. Ultrasonicator and Mechanical stirrer forpreparation of nano fuel blends.

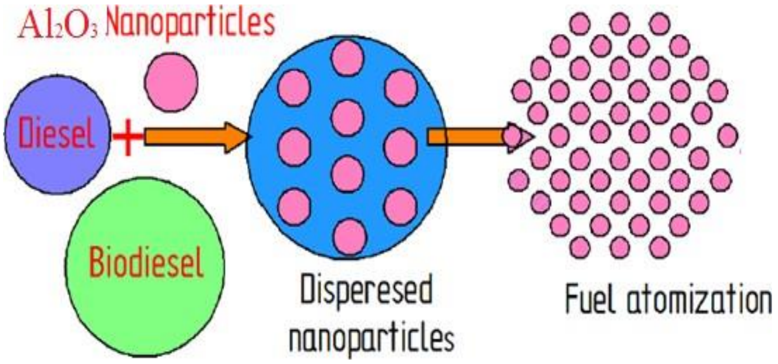

Figure 3.2.Atomization of nanoparticles dispersedtest fuel.

Identification and Preparation of Chlorella Green Microalgae Biofuel:

The process of identifying and preparing Chlorella green microalgae biofuel involved several steps. Initially, algae samples were examined under an Eclipse E200 Compound Microscope, and photographs were taken at 40 times and 100 times magnification, as shown in Figure 1.

Subsequently, the collected algae samples were spread under the sun on the roof of the hostel for 48 hours (2 days) to allow for evaporation of water content. Once dried, the samples were ground using a pestle and grinder until a fine powder was obtained. This powder was then sieved through different micron sieves to obtain various mesh sizes of algal biomass, as depicted in Figure 2.

After grinding, the algae powder was dried for an additional 30 minutes at 80°C in an incubator to remove any remaining moisture. Finally, the dried algae powder was stored in sealed containers for use in extraction experiments.

Figure:3.4Collection of algae from theopen pond

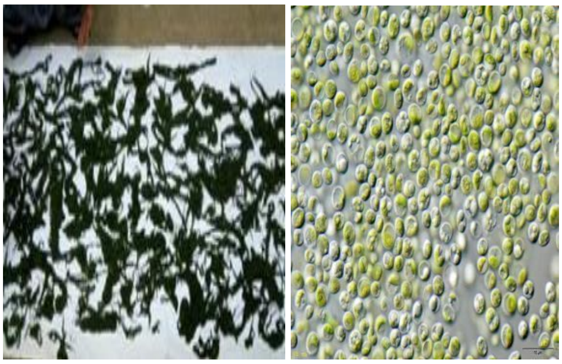

Figure.3.5Chlorella green microalgae bio fuel identification and drying associated with the algalbiomass.

Oil extraction from Algae:

The collected algae samples were dried completely (100%) and then powdered. Hexane was mixed with the dried ground algae to extract the oil in a separating funnel with a capacity of 250 ml. The mixture was then left to settle for 24 hours to allow for the separation of the two layers in the funnel. The organic phase containing the algae oil was then transferred into a pre-weighed 50 ml beaker. The algal oil was separated from the algae biomass by filtration, and its weight was determined using an electronic weight balance.

Fig :3.6 samples

Nanoparticle Size Analysis using XRD:

XRD analysis was conducted utilizing the X'pert powder XRD method, employing a PANalytical X-Ray diffract meter with Co-Kα radiation within the range of 10–90°. This analysis aimed to examine the crystal structure, size, and purity of the acquired Al2O3 nanoparticles. To evaluate the crystalline size, an X-Ray beam was directed through a nanoparticle sample with a wavelength of 0.15 nm. The XRD patterns of the obtained Al2O3 nanoparticles are specifically depicted in Fig. [Insert Figure Number]. All peaks observed in the XRD analysis were carefully examined.

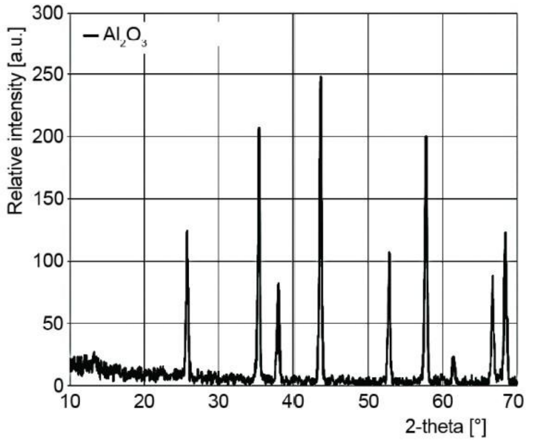

Fig3.7. XRD patterns for Al2O3 nanoparticle

Patterns clearly demonstrate a good crystal structure of both nanoparticles and detect no peaks of impurities. Therefore, the XRD test results show that the purity of purchased nanoparticles exceeds 99%. The Al2O3 nanoparticles obtained sizes of 50 nm and 27 nm, respectively.

A mixture of Al2O3 nanoadditive with neem biodiesel utilizes an ultrasonic 20 kHz homogenizer (SONOPULS- HD2070). This process also aids in improving the stability of the nanoadditive with neat biodiesel. One liter of biodiesel blend was utilized for each test run. In between the test runs, diesel fuel was run through the engine to clear the deposits of the biodiesel blends in the fuel tank, engine, and oil passages. This procedure also helps to increase the engine temperature, which in turn is useful for the combustion of higher viscosity biodiesel.

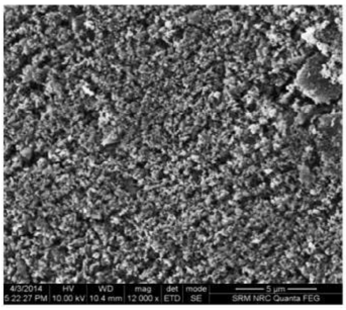

Fig3.8: The SEM image

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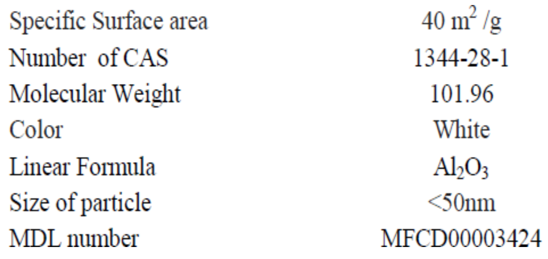
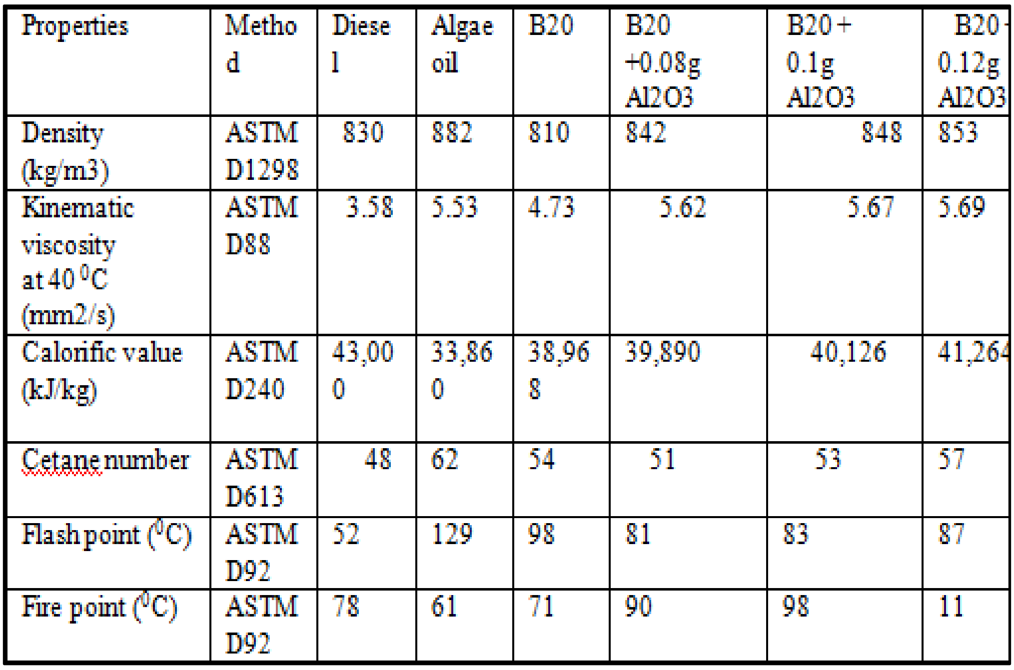
Details of Al2O3 nanoparticle



Specific Surface area	40 m^2 /g
Number of CAS	1344-28-1
Molecular Weight	101.96
Color	White
Linear Formula	Al_2O_3
Size of particle	<50nm
MDL number	MFCD00003424

The physical and chemical properties were measured based on ASTM standards for diesel and algae biodiesel blend B20 and its Al2O3 blend fuels.

Table 3.2: Physical and chemical properties of diesel and algae oil and its blend



Properties	Method	Diesel	Algae oil	B20	B20 +0.08g Al2O3	B20 + 0.1g Al2O3	B20 0.12g Al2O3
Density (kg/m3)	ASTM D1298	830	882	810	842	848	853
Kinematic viscosity at 40 ^{0}C (mm2/s)	ASTM D88	3.58	5.53	4.73	5.62	5.67	5.69
Calorific value (kJ/kg)	ASTM D240	43,000	33,860	38,968	39,890	40,126	41,264
Cetane number	ASTM D613	48	62	54	51	53	57
Flash point (^{0}C)	ASTM D92	52	129	98	81	83	87
Fire point (^{0}C)	ASTM D92	78	61	71	90	98	11

Problems with Emissions:

1. **Carbon Monoxide (CO):** Carbon monoxide is a poisonous gas that lacks odor but can be lethal without detection. The primary solution to carbon monoxide emissions from petrol engines has been the implementation of catalytic converters, but they come with their own set of drawbacks:
    - Increased fuel consumption.
    - Prone to easy poisoning and subsequent malfunction.
    - Susceptible to mechanical damage.
2. **Nitrogen Oxides (NOx):** Nitrogen is a major component of the air we breathe. When exposed to high pressures and temperatures with oxygen in the air, it forms nitrogen oxides. These oxides later combine with ozone to form smog. Diesel engines, due to their high air content during operation, are more likely to produce nitrogen oxides. Exhaust Gas

Recirculation (EGR) systems reduce the combustion temperature below the point where nitrogen can effectively burn.

3. **Hydrocarbons (HC):** Hydrocarbon emission levels vary with the equivalence ratio for an SI engine. There is significant activity in wind energy ratio, where fuel additive mixtures lack sufficient oxygen to fully oxidize all carbon compounds, resulting in the production of final exhaust products such as HC and CO. This is particularly evident during richer air-fuel mixture starts and least pronounced during low-load and less rapid acceleration.
4. **Carbon Dioxide (CO2):** Carbon dioxide (CO2) constitutes the majority of greenhouse gas emissions from various sectors, although smaller amounts of methane (CH4) and nitrous oxide (N2O) are also released. These gases are emitted during the combustion of fossil fuels such as coal, oil, and natural gas to generate electricity.
5. **Particulate Matter (PM):** Particulate matter refers to solid particles and liquid droplets present in the air. These airborne particles and droplets vary in composition and size, with two commonly monitored size ranges known as PM10 and PM2.5. Monitoring of these particulate matter sizes is conducted both at major emissions sources and in ambient air.

Experimental Setup:

Experiments were conducted on a Kirlosker water-cooled single-cylinder diesel engine with a 4-stroke configuration. The specifications of the engine are detailed in Table 1. The experimental setup is illustrated in the figure.

To maintain engine control, a steady speed of 1500 rpm was utilized. Tests were conducted on the diesel engine using Al2O3 nanoparticle substitutes and algae oil, with loads ranging from 0 to 12 kW. The motor was connected to an electrical dynamometer to apply the brake load.

Two different fuel tanks were employed for diesel fuel and sesame oil. A 50 cm3 burette and a stopwatch were utilized for measuring the volumetric fuel flow rate. Emissions, including CO, HC, and NOx, were analyzed using the AVL-444 5 gas analyzer, while smoke levels were measured using the Bosch smoke pump, with the smoke meter attached to the engine's exhaust manifold.

Fig :4.1Kirlosker engine experimental setup

Table 4.1: Specifications of Test Engine

Parameter	Value
Power (KW)	3.3 KW
Bore (mm)	87.50
Stroke (mm)	110.00
Compression Ratio	18:0
Speed	1500
Injection Pressure (Bar)	200
Injection Timing	230 BDC

Combustion Parameters:

- Specific Gas Const (kJ/kg K): 1.00
- Air Density (kg/m3): 1.17
- Adiabatic Index: 1.41
- Polytrophic Index: 1.06
- Number Of Cycles: 10
- Cylinder Pressure Reference: 5
- TDC Reference: 0

Performance Parameters:

- Orifice Diameter (mm): 20.00
- Orifice Co-eff. Of Discharge: 0.60
- Dynamometer Arm Length (mm): 185
- Fuel Pipe Diameter (mm): 12.40
- Ambient Temp. (°C): 29
- Pulses Per Revolution: 360
- Fuel Type: Diesel
- Fuel Density (Kg/m3): 830
- Calorific Value Of Fuel (kJ/kg): 43,000

Experimental Procedure:

Experiments were conducted using both diesel and algae biodiesel. The tests were carried out on the engine. The experimental investigation proceeded in stages:

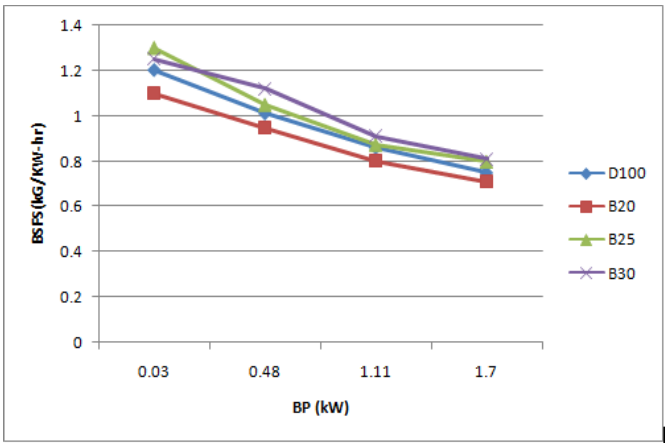
1. **Baseline Parameters:** In the first stage, baseline parameters were obtained using standard diesel.
2. **Waste Fish Biodiesel Blends:** In the second stage, waste fish biodiesel blends (B20, B25, and B30) were used as fuel in the engine.
3. **Algae Biodiesel with Al2O3 Additive:** In the third stage, algae biodiesel with Al2O3 additives at concentrations of 80 ppm, 100 ppm, and 120 ppm were used as fuel in the engine.

The engine cooling was achieved by circulating water through the jackets of the cylinder head and the engine block. Various instruments were utilized for the measurement of different parameters during the experimental investigations. The major gaseous emissions measured included HC, CO, CO2, and NOx. The occurrence of these emissions depends on factors such as the type of fuel used, engine operating and design conditions, and engine loading conditions.

5. RESULTS AND DISCUSSIONS

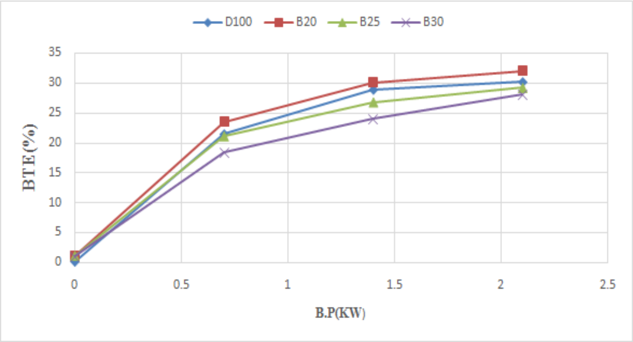
Performance Analysis of Bio-Diesel Blends

Graph 5.1 BP Vs BSFC The graph illustrates the relationship between Brake power and Brake specific fuel consumption (BSFC). It compares the BSFC of various fuels (D100, B20, B25, B30) used in the diesel engine. BSFC measures the amount of input energy required to develop one kilowatt of power. The graph shows that as brake power increases, BSFC decreases, and this trend holds true for all test loads. Biodiesel blend B20 exhibits lower BSFC than diesel (D100) fuel under loading conditions.



Graph 5.1 BP Vs BSFC

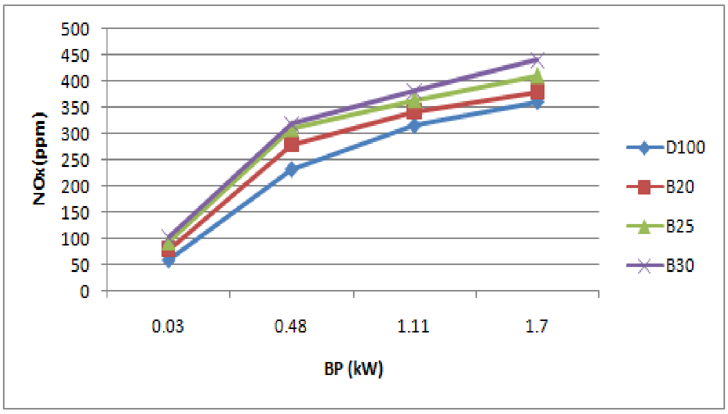
Graph 5.2 BP Vs BTE This graph displays the relationship between Brake power and Brake thermal efficiency (BTE). It compares the BTE of various fuels (D100, B20, B25, B30) used in the diesel engine. As brake power increases, BTE also increases. This increase in BTE is attributed to the higher oxygen content in test fuels and engine loads. BTE increases with load due to a reduction in heat loss and an increase in power. Biodiesel blend B20 shows lower BTE than diesel (D100) fuel under loading conditions.



Graph 5.2 BP Vs BTE

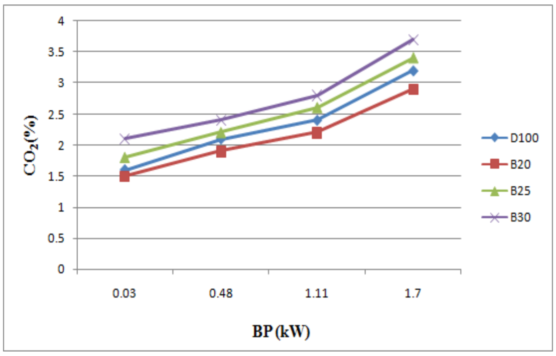
Emission Characteristics of Bio-Diesel Blends

Graph 5.3 B.P Vs NOX This graph illustrates the relationship between Brake power and NO_x emissions. It compares the NO_x emissions of various fuels (D100, B20, B25, B30) used in the diesel engine. NO_x emissions increase with brake power, with biodiesel exhibiting higher NO_x levels compared to diesel operation. The increase in NO_x emissions during biodiesel operation is attributed to its reactive nature at higher temperatures and the presence of oxygen in its structure. Biodiesel blend B20 with 100ppm of Al2O3 additive shows lower NO_x emissions compared to other additives at higher loads.



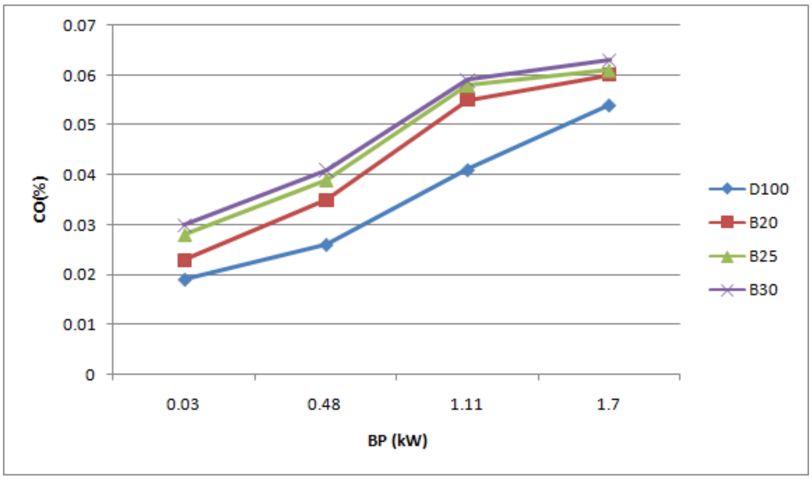
Graph 5.3 B.P Vs NOX

Graph 5.4 B.P vs CO2 This graph compares the CO2 emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) used in the diesel engine against brake power. As expected, CO2 emissions increase with load due to higher fuel consumption associated with load increase. Biodiesel blend B20 with 100ppm nano additive exhibits lower CO2 emissions compared to other additive blends under similar load conditions.



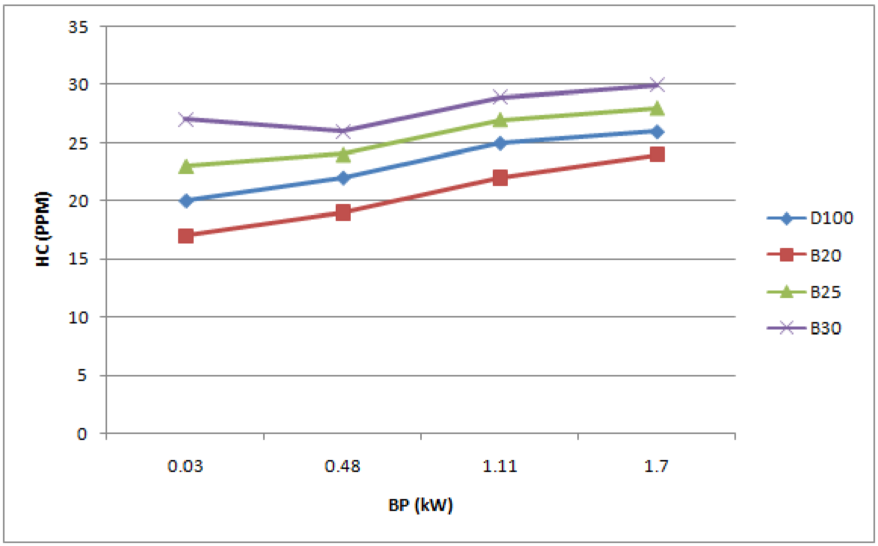
Graph5.4 B.P vs CO_2

Graph 5.5 B.P Vs CO This graph compares the CO emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. CO emissions increase with increasing loads, attributed to the decrease in air-fuel ratio. Biodiesel blend B20 emits marginally higher CO emissions compared to diesel at higher loads.



Graph 5.5 B.P Vs CO

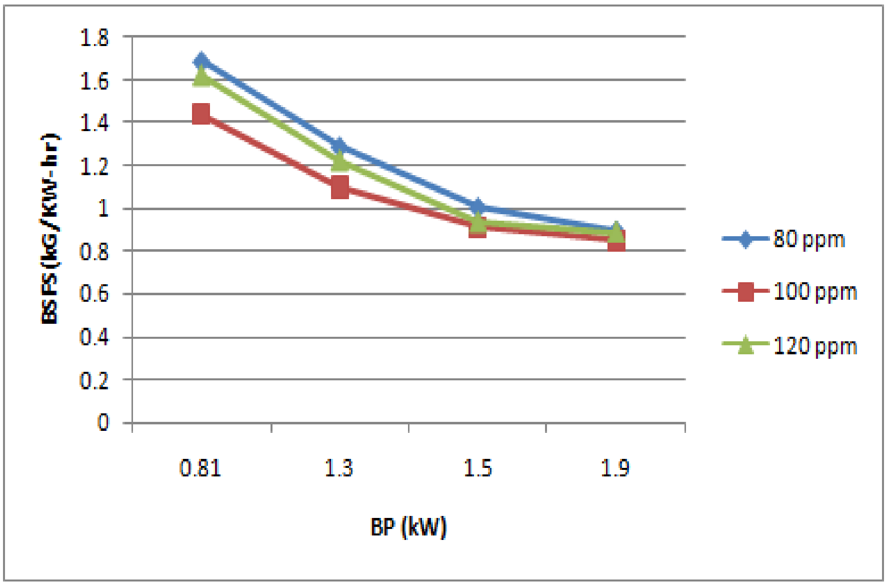
Graph 5.6 B.P Vs HC The graph shows the relationship between brake power and hydrocarbon (HC) emissions for various fuels (B20+80ppm, B20+100ppm, B20+120ppm). HC emissions decrease for biodiesel blends due to their higher cetane number and longer ignition delay, promoting complete oxidation. Biodiesel blend B20 with 100ppm additive exhibits lower HC emissions compared to other additive blends.



Graph 5.6 B.P Vs HC

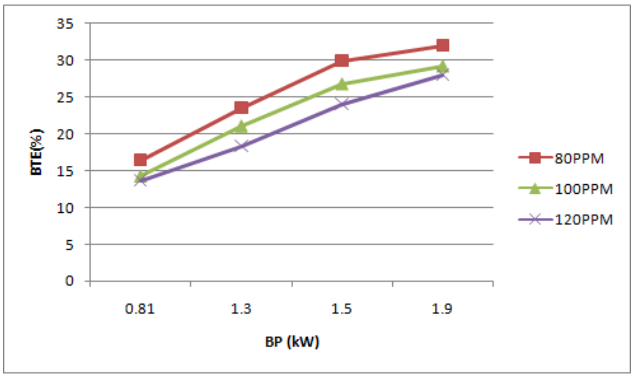
Performance And Emission Characteristics With Aluminium Oxide As Nano Additive

Graph 5.7 B.P Vs BSFC This graph compares the BSFC of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. It shows that BSFC decreases with increasing load, with algae biodiesel B20 with 100ppm of Al2O3 additive exhibiting the minimum BSFC compared to other additive percentages under loading conditions.



Graph 5.7 B.P Vs BSFC

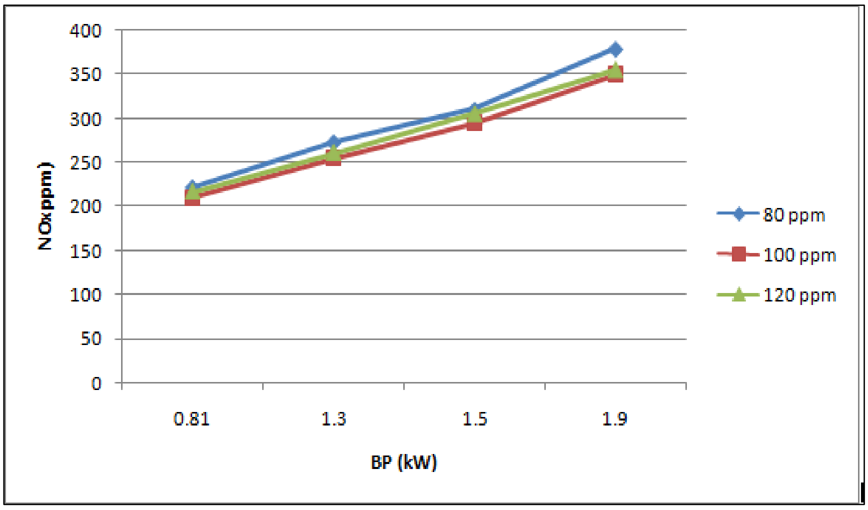
Graph 5.8 B.P Vs BTE The graph compares the BTE of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. BTE increases with load for all tested fuels, with algae biodiesel B20 with 100ppm of Al2O3 additive exhibiting the minimum BTE compared to other additive percentages under loading conditions.



Graph 5.8 B.P Vs BTE

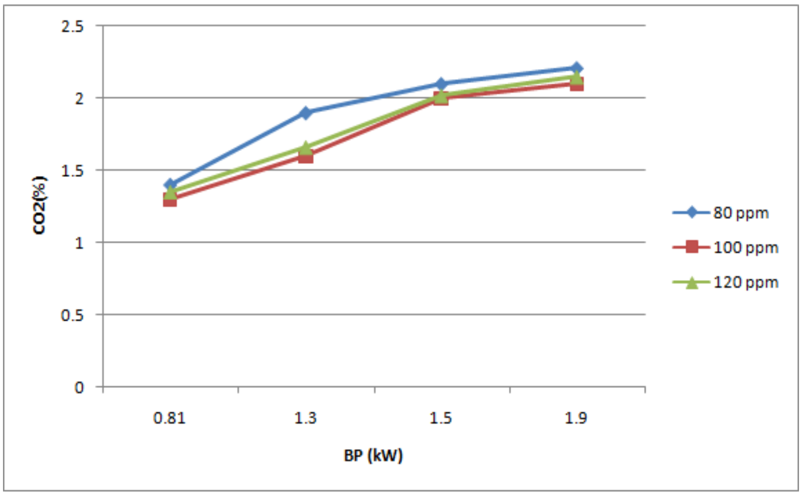
Emission Analysis With Additive

Graph 5.9 B.P Vs NOx This graph illustrates the NO_x emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. By adding aluminium oxide (Al2O3), there is a reduction in NO_x emission, with algae biodiesel B20 with 100ppm additive showing less NO_x emissions than other additives at higher loads.



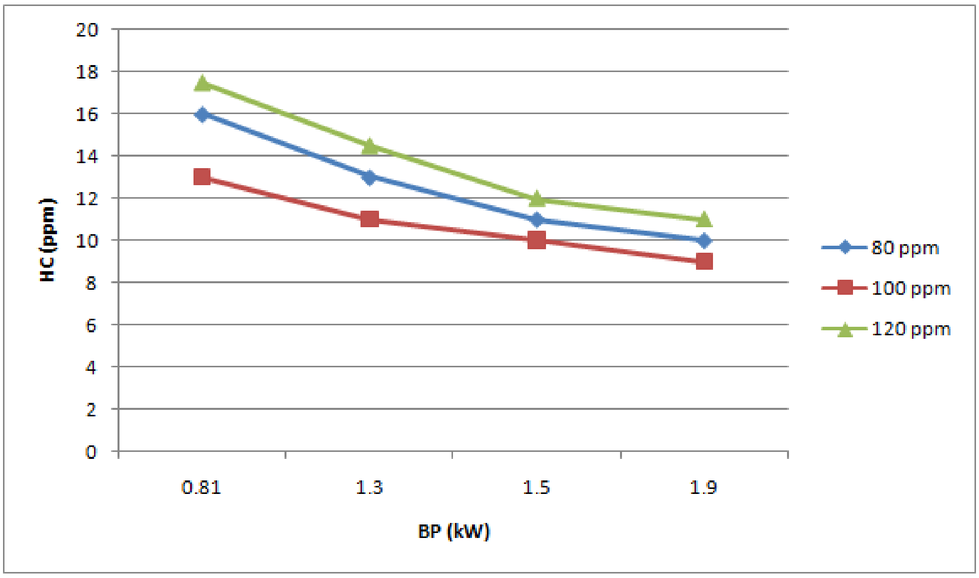
Graph 5.9B.P Vs NOx

Graph 5.10 B.P Vs CO2 This graph compares the CO2 emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. CO2 emissions increase with load, with algae biodiesel B20 with 100ppm nano additive showing lower CO2 emissions compared to other additives.



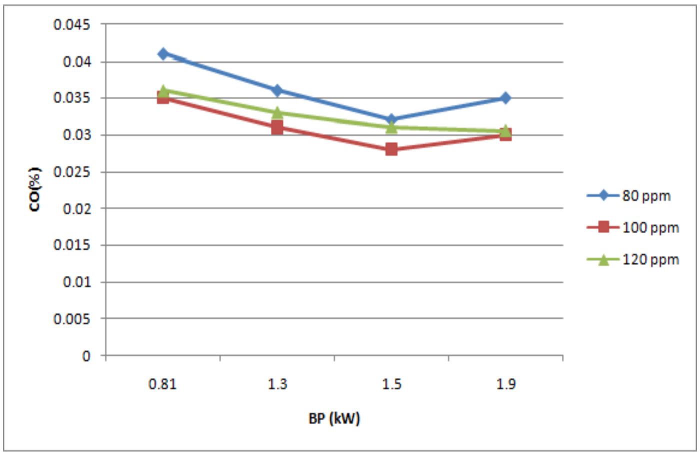
Graph 5.10 B.P Vs CO2

Graph 5.11 B.P Vs HC This graph compares the HC emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. Biodiesel blend B20 with 100ppm additive exhibits lower HC emissions compared to other additive blends, attributed to its higher cetane number and longer ignition delay.



Graph 5.11 B.P(KW) Vs HC (ppm)

Graph 5.12 B.P Vs CO This graph compares the CO emissions of various fuels (B20+80ppm, B20+100ppm, B20+120ppm) against brake power. At lower loads, biodiesel blend B20 with 100ppm additive exhibits higher CO emissions due to lower in-cylinder temperature and poor atomization. However, at higher loads, CO emissions decrease for this blend due to improved cylinder temperature and oxygen concentration.



Graph 5.12 BP(KW) VS CO(%)

6. CONCLUSIONS

In this present investigation, biodiesel extracted from Chlorella algae is tested in a single-cylinder diesel engine. The initial part of this study involved the analysis of the physical and chemical characteristics of diesel and algae blends, along with aluminum oxide as a nano additive. Experimental studies were then carried out by running the engine at various load conditions, and the corresponding performance and emission characteristics were studied. The various conclusions made from the present study are as follows:

Performance and Emission Characteristics of Bio-Diesel Blends:

- As applied load increases, brake specific fuel consumption (BSFC) decreases for both algae blends and diesel. Among the blends, algae biodiesel B20 shows better results, with a marginally lower BSFC compared to diesel at maximum load conditions.
- Brake thermal efficiency (BTE) increases with applied load for both algae blends and diesel. Algae biodiesel B20 exhibits better BTE compared to diesel, with a slightly higher value at maximum load conditions.
- Nitrogen oxide (NOx) emissions increase with applied load for both algae blends and diesel. Algae biodiesel B20 shows slightly higher NOx emissions compared to diesel at maximum load conditions.
- Carbon dioxide (CO2) emissions increase with applied load for both algae blends and diesel. Algae biodiesel B20 exhibits slightly lower CO2 emissions compared to diesel at maximum load conditions.
- Carbon monoxide (CO) emissions increase with applied load for both algae blends and diesel. Algae biodiesel B20 shows slightly higher CO emissions compared to diesel at maximum load conditions.
- Hydrocarbon (HC) emissions increase with applied load for both algae blends and diesel. Algae biodiesel B20 shows slightly lower HC emissions compared to diesel at maximum load conditions.

From the above studies, it is concluded that algae biodiesel blend B20 shows better results when compared with diesel and other blends. However, it has slightly higher emissions (CO and NOx) values compared to diesel. Therefore, aluminum oxide is used as a nano additive with algae biodiesel blend B20 to reduce emissions.

Performance and Emission Characteristics of Algae Biodiesel Blend B20 with Aluminum Oxide Additive (80ppm, 100ppm, 120ppm):

- As applied load increases, brake specific fuel consumption (BSFC) decreases for algae biodiesel blend B20 with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive shows the best results in terms of BSFC.
- Brake thermal efficiency (BTE) increases with applied load for algae biodiesel blend B20 with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive exhibits the best BTE results.
- Nitrogen oxide (NOx) emissions increase with applied load for algae biodiesel blend B20 with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive shows better NOx emission results.
- Carbon dioxide (CO2) emissions increase with applied load for algae biodiesel blend B20

with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive exhibits better CO2 emission results.
- Carbon monoxide (CO) emissions show a decreasing trend with applied load for algae biodiesel blend B20 with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive shows better CO emission results.
- Hydrocarbon (HC) emissions decrease with applied load for algae biodiesel blend B20 with additives (80ppm, 100ppm, 120ppm). Among the additives, 100ppm nano additive shows better HC emission results.

From the above studies, it is concluded that algae biodiesel blend B20 with 100ppm aluminum oxide nano additive is effective compared to other additives.

REFERENCES

[1] Gaurav Dwivedi, Siddharth Jain, M.P. Sharma, "Diesel engine performance and emission analysis using biodiesel from various oil sources – Review", *J. Mater. Environ. Sci.*, 2013, 4, 434-447.
[2] Barnwal B K and Sharma M P., "Prospects of Biodiesel Production from Vegetable oil in India", *Renewable and Sustainable Energy Reviews*, 2005, 9, 363-378.
[3] Avinash Kumar Agarwal, "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines", *Progress in Energy and Combustion Science*, 2007, 233–271.
[4] Murugesan A, Umarani C, Subramanian R, "Biodiesel as an alternate fuel for diesel engines-A review", *Journal of Renewable and sustainable energy reviews*, 2009, 653-662.
[5] I.M. Rizwanul Fattah, H.H. Masjuki, A.M. Liaquat, Rahizar Ramli, M.A. Kalam, V.N. Riazuddin, "Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions", *Journal of Renewable and Sustainable Energy Reviews*, 18, 2013, 552–567.
[6] Md. Nurun Nabi, Md. Mustafizur Rahman, Md. Shamim Akhter, "Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions", *Applied Thermal Engineering*, 2009, 29, 2265–2270.
[7] T. Venkateshwara Rao, G. prabhakarrao, K. Hema Chandra reddy. "Experimental investigation of pongamia, Jatropa, Neem methyl esters as biodiesel in CI engine", *JJMIE*, 2008, 2, 117-122.
[8] A.E. Atabani, A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, Irfan Anjum Badruddin, H. Fayaz, "Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production", *Renewable and Sustainable Energy Reviews*, 2013, 18, 211–245.
[9] Yie Hua Tan, Mohammad Omar Abdullah, Cirilo Nolasco-Hipolito, Nur Syuhada Ahmad Zauzi, Georgie Wong Abdulla, "Engine performance and emissions characteristics of a diesel engine fueled with diesel-biodiesel-bioethanol emulsions".
[10] Rao et al, G. L. K., "Relationships among the physical properties of biodiesel and engine fuel system design requirement", *International Journal of Energy And Environment*, 2010, 1, 919-926.
[11] Ganesh, G. Gowrishankar, "Effect of Nano-fuel additive on emission reduction in a Biodiesel

fuelled CI engine", 2011, IEEE, DOI: 10.1109/ICECENG.2011.6058240.

[12] Kumar B Rajesh, Saravanan S, Rana D, Anish V and Nagendran A, "Effect of a sustainable biofuel – n-octanol – on the combustion, performance and emissions of a DI diesel engine under naturally aspirated and exhaust gas recirculation (EGR) modes", *Energy Conversion and Management*, 2016, 118, 275–86.

[13] J. Sadhik Basha, R. B. Anand, “The influence of nano additive blended biodiesel fuels on the working characteristics of a diesel engine”, *Braz. Soc. Mech. Sci. Eng.*, 2013, 35, 257–264.

[14] Sadhik Basha J, Anand RB, "Performance and emission characteristics of a DI compression ignition engine using carbon nanotubes blended diesel", *Int J Adv Ther Sci Eng*, 2010, 1, 67–76.

[15] DeLuca LT, Galfetti L, Severini F, "Combustion of composite solid propellants with nanosized aluminium", *Combust Explos Shock Waves*, 2010, 41, 680–692.