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Nano-Curcumin as a Green Additive for Algae Biodiesel: Experimental Insights into Diesel Engine Combustion and Emission Performance

Ramesh, C.[1]*, Dhamodharan, N.[2], Velmurugan, S.[3], Ramachandra Raju, K.[3], Subramaniyan Chinnasamy[3], Prakash, K. B.[3] and Arul. M.[4]

[1]Department of Mechanical Engineering, K.S.Rangasamy College of Technology, Tiruchengode, Tamil Nadu 637215, India

[2]Department of Automobile Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, Tamil Nadu 642003, India

[3]Department of Mechanical Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Erode, Tamil Nadu 638401, India

[4]Department of Mechanical Engineering, ARM College of Engineering and Technology, Maraimalainagar, Chennai, Tamil Nadu 603209, India

*Corresponding author (e-mail: rameshcr238@gmail.com)

The present work experimentally investigated the single cylinder diesel engine characteristics fueled with green energy from *Botryococcus braunii* micro algae. Aquatic unicellular green algae have a high growth rates and high population densities in sea. Mechanical expeller is used to covert the algae into oil at normal temperature and pressure. Due to higher viscosity, higher flash point and low calorific value of algae oil is not suitable for diesel engine fuel. So, it can be converted into biodiesel using transesterification process with help of KOH as a catalyst and ethanol as a solvent. After the transesterification process, the oil reduced the viscosity, flash point and increased calorific value compared with algae oil. Prepared the test fuel samples for different blends ratios like B10, B20 and B30. Analyses the physical and chemical properties of the test fuel as per the ASTM standard compared with diesel presented in this paper. A single cylinder direct injection diesel engine producing max power of 3.4 KW at rated speed of 1500 rpm used as test engine with green fuel. The exhaust emission like CO, CO2, HC, NOx and Smoke are to measure by using AVL 444 DI gas analyzer and AVL 437 Smoke meter. Experimental results proved that B20 as the best blend ratio compared to B10 and B30.In phase 2 the B20 blend is blended with the curcumin nano particle with 25 ppm to 100 ppm to attain the high efficiency and lower emission in the diesel engines. The brake thermal efficiency increased by 6.5 % compared to B20 and B20 with 50ppm curcumin nano additives. The emissions of CO, CO_2, HC, NOx and smoke are reduced by 3.2%, 4.2%, 5.3%, 8.34% and 7.23% compared to B20 blend bio diesel without any engine major modifications are discussed in this paper.

Keywords: *Botryococcus braunii* algae, transesterification, engine characteristics, green fuel, curcumin nano additives

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The high amount of population and industrialization transportation plays a major role for the country. For the transportation the fuel economy will decide the cost of the products. In this fuel price increases will impinge on the pockets of households. They would spend more on fuel and cut expenditure on other items. This will impact GDP as consumption demand accounts for 57-58 per cent in it [1]. It has long been accepted that using liquid fossil fuel as a source of energy is unsustainable, and more critically, that the amount of liquid fossil fuel available would be depleted by the middle of this century and also fossil fuels are burned, they release large amounts of carbon dioxide, a greenhouse gas, into the air. Greenhouse gases trap heat in our atmosphere, causing global warming. Already the average global temperature has increased by 1°C [2]. So that the world moving to the next generation of fuels to reduce the emission and also increasing the performance of the engine. The algae because of their quick growth, potential to repair greenhouse gases and high lipid production rate, microalgae are presently being marketed as an attractive third generation biofuel feedstock. They may be produced on infertile soil and in salty water, and they don't compete with food or feed crops [3]. Microalgae are effective photosynthetic microorganisms that may be used to purify the air by producing O_2 and reducing CO_2 and hazardous substances like SOx and NOx [4]. The section of micro algae depends upon the growth time and

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observing the amount of CO2 and also high amount of yield to produce the bio diesel. Depending upon the criteria the *Botryococcus braunii* algae can satisfy the process [5]. Algae can be growth in fresh water, reservoir and ponds, also grow up the algae in laboratories easily. Extract the oil from the dried algae using solvent as a medium. The algae oil has some lipids and oil contents. These are all converted into fatty acids and esters using the transesterification process. After that blend has been mixed into the diesel various level like B20, B30 and B40. In this Bio diesel blend has 20,30,40 percentages of *Botryococcus braunii* algae oil and 80,70,60 percentage of diesel [6]. These fuels are using for the diesel engine to identify the performance and emission characteristics. Finally; the performance and emission characteristics of the engine has been carried out with bio diesel and compared to the pure diesel fuel. Compare to the other algae's *Botryococcus braunii* algae is observed high amount of CO_2 and emits the high amount of O_2 to the environment, also this algae gives the high amount of yield to produce the biodiesel [7].

MATERIALS AND METHODS

Algae Oil Preparation

Botryococcus braunii, a colonial green microalga, is found in fresh - water and coastal ponds and lakes all over the world, frequently in enormous floating masses. *Botryococcus braunii* develops best at 23 °C, 60 W/m^2 of luminosity, 12 hours of sunlight each and every day, and 0.15 molar NaCl salt, according to studies in the laboratory can grow up the algae mention in Figure 1. The expeller press, often known as an oil press, is one of the easiest and oldest techniques used to extract oil from algae [8]. Mechanical crushing, a simple but successful process, is also utilized in the extraction of the oil from algae biomass. The oil content of dried algae biomass may be extracted using an oil press. The basic idea behind this technology is to use high mechanical pressure to crush and shatter the cells and squeeze the oil out of the algae biomass. The applying of pressure in a certain range enhances extraction efficiency [9]. The procedure converts the carbon in algae into usable crude oil by using heating at 350 °C and high intensity of 20 MPa. It is a prospective source of renewable fuel since it generates hydrocarbon oils at 25-75% of its dry weight.

Figure 1. Laboratory Cultivation.

Chemical Properties

Table 1. Compares the chemical characteristics of algae oil, algae biodiesel, and diesel to ASTM biodiesel criteria[10].

Properties	Algae oil	Algae Biodiesel	Diesel	ASTM Biodiesel std.
Appearance	Translucent	Translucent	Clear	Translucent
Color	Yellow/ Greenish	Greenish Yellow	Yellowish	Greenish Yellow
Kinematic viscosity, 40°C (cSt)	37.74	4.25	1.9 to 4.1	3.5 to 5.5
Acid no. (mg KOH per g)	0.3	0.385	Max 0.5	Max 0.5
Calorific value (MJ/kg)	35.8	36.5	43.5	37.5
Flash Point (°C)	224	116	75	Min 100
Density (kg/lit)	0.858	0.848	0.830	0.862– 0.9

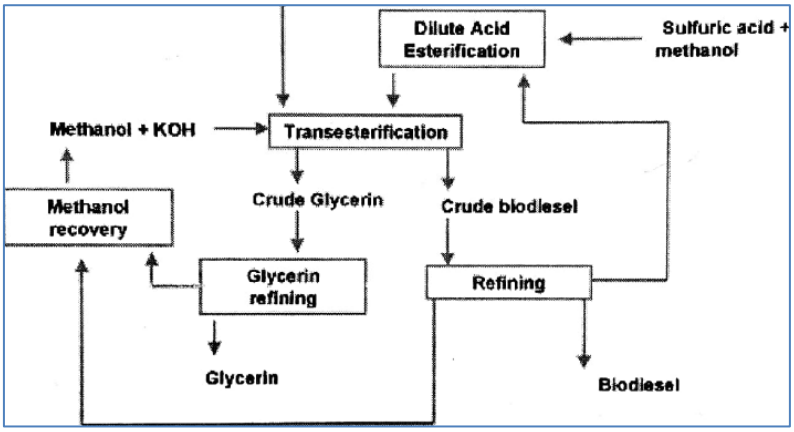

Figure 2. Transesterification process of *Botryococcus braunii* micro algae.

Figure 3. Transesterification Process brunii algae bio diesel.

Transesterification Process

Pre-esterification and transesterification were used to convert algae oil with a high free fatty acid content to biodiesel. During the process with 2% of KOH used as a catalyst at 65 °C for 30 minutes, the conversions of triglycerides achieved 100% with a methanol to oil molar ratio of 12:1 [11].

In this process the triglycerides in the algae oil are reacts with an alcohol mixture poured into the glass bowl after that 2% volume of KOH is mixed with that glass bowl and stirrer vastly. This mixture is heated at 65 °C using the induction for 30 minutes of time. Above the reaction is completed, the principal co-products, biodiesel and glycerin separated into two layers. After being separated from the glycerin, the biodiesel is cleaned to eliminate excess alcohol, residual catalyst, and soaps shows in the Figure 3. This contains one or more clean water washings. It then goes through another distillation phase to generate a colorless, odorless biodiesel free of Sulphur [12].

Blend Preparation and Experimental Setup

The blend has prepared to mix with the diesel; three types blends has been tested with the engine. B10 blend is prepared by 10% volume of *Botryococcus braunii* biodiesel and 90 % volume of diesel are blended. Also B20 and B30 are prepared as per the process[13]. First of all, the engine performance and emission characteristics are identifying with pure diesel as fuel. After that B10, B20 and B30 blended biodiesels are used as a fuel and compared with the pure diesel. The required amount of curcumin nanoparticles is taken by using the electronic weighing machine. Four various amounts of curcumin nanoparticles were mixed with the algae bio diesel blend as 25ppm, 50ppm, 75ppm and 100ppm. In a algae bio diesel blend 25 mg of curcumin nano particle were mixed with the 1 litre of bio diesel blend is considered as 25ppm. The same methodology all the four classifications of curcumin nano particles are added to the bio diesel blend. To prevent the nano particle agglomeration and to attain the uniform mixing in the bio diesel blend, the mixture was under the process of ultrasonication for 30 min to 45 min. It

will help to improve the nano particle mix with the fuel. The mixers are filled with the air tight containers used to identify the engine performance and emission characteristics.

The current experimental investigation made use of a Kirloskar model diesel engine attached to an eddy-current dynamometer for loading. The diesel engine was set to run at 1500 rpm with a maximum output of 3.5 kW. The arrangement included transmitters for measuring air and fuel flow[14]. The rota meters were used to measure the temperature of the cooling water. The data acquisition system was linked to the engine, and the programme presented the pressure volume and pressure crank angle curves. The quantity of emissions of exhaust gases was measured using a 444 DI – Gas analyzer and a smoke metre. A four-stroke, single-cylinder, direct injection, water-cooled, naturally aspirated CI engine was employed in the testing. It had an 87.5 mm bore and a 110 mm stroke. The maximum power delivered by the engine was about 3.5 kW at a constant speed of 1500 rpm and the compression ratio of 16.5:1.

RESULT AND DISCUSSION

The *Botryococcus braunii* algae oil was prepared and the algae oil blend with the diesel for the experimental purpose. In the single cylinder 4 stroke water cooled diesel engine were used as the experimental setup and the different blends of algae bio diesel B10, B20 and B30 are used as the fuel mixtures for the diesel engine and compare the performance characteristics and emissions characteristics are compared with the pure diesel as fuel. Here using 9 samples were tested and for the accuracy of the experimental analysis test were taken for 5 times repeatedly.

Impact of Algae Bio Diesel Blend

Observed from the Figure 4, the experiment has run in the four-stroke single cylinder diesel engine, comparison of pure diesel, B10, B20 and B30 brake thermal efficiency with respect to the brake power is mentioned. From the graph, B20 blend has the high brake thermal efficiency compare to the Diesel, B10 and B30 biodiesel blends. Limited amount of biodiesel blends 20% of volume compare to the other blends, high amount of burning of fuel in the combustion chamber. The biodiesel blend B20 has high brake thermal efficiency of 4.5 % compared to the other blend B10 and B20 at 90 % of load condition. B20 has the extra oxygen content to improve the complete combustion in the combustion chamber. Compare to B20, B30 and higher proportion has the high fuel density and viscosity, the combustion process moves to slower and reducing the efficiency.

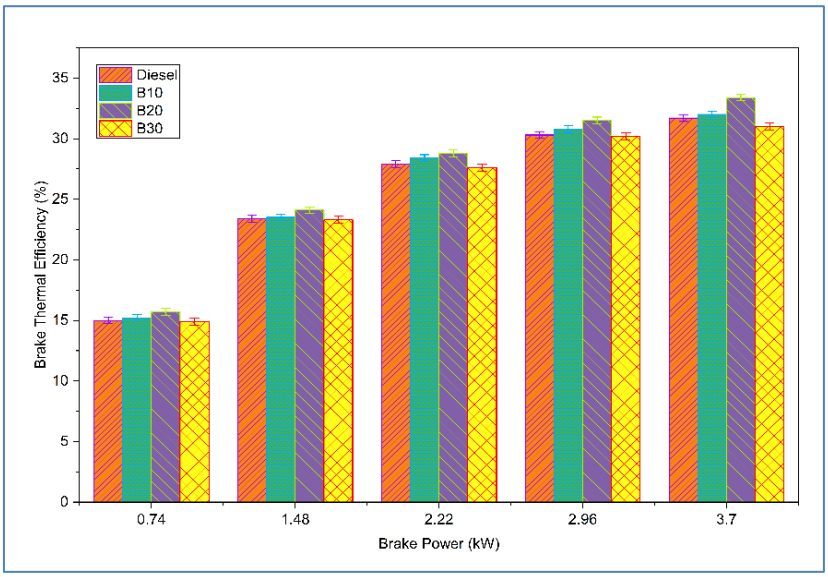

Figure 4. Brake power vs Brake Thermal Efficiency.

Attained the results from the Figure 5, compared to the pure diesel, B10 and B30, B20 has the lower carbon monoxide emission. Its reduction because of the algae bio diesel has the high amount of oxygen content in the blend, it will increase the combustion process completely, so that the formation of carbon monoxide is reduces. Compare with the B10 and B30, the blend B10 having the lower amount of oxygen compare to the B20, it's not sufficient to produce the complete combustion. But the blend B30 has the high amount of oxygen, the calorific value of the fuel blend has been decreasing to reduce the speed of the combustion process. The fuel blend B20 have the balanced oxygen content to attain the complete combustion process. Apparent from the Figure 6, B20 blend has the lower emission of carbon dioxide for the same operating conditions compare to the diesel, B10 and B30. The B20 blend has the high amount of oxygen content, it will increase the high calorific value and viscosity the complete combustion has been rushed and the emissions like carbon dioxide was reduced. The amount of carbon filled in the algae bio diesel blend is fully oxidized, so that B30 blend has the high amount of carbon dioxide emission compare to the B20 algae bio diesel blend. Better atomization of the B20 blend gives the result of increase of engine efficiency.

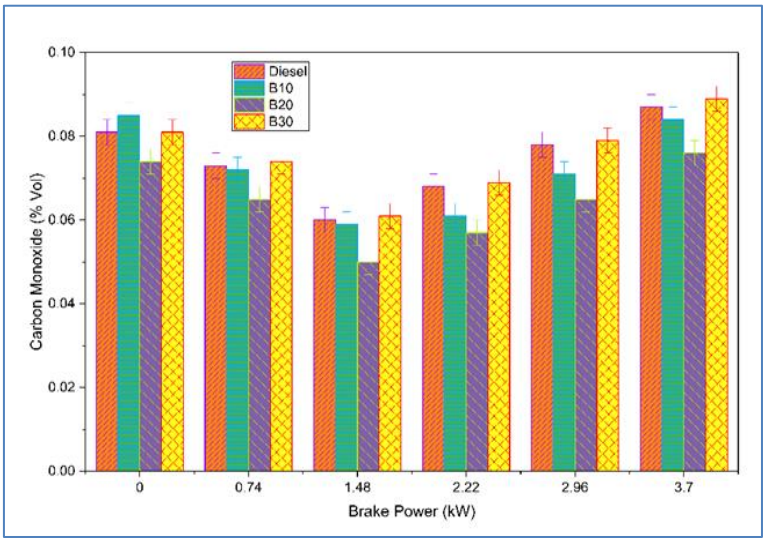

Figure 5. Brake power vs Carbon Monoxide.

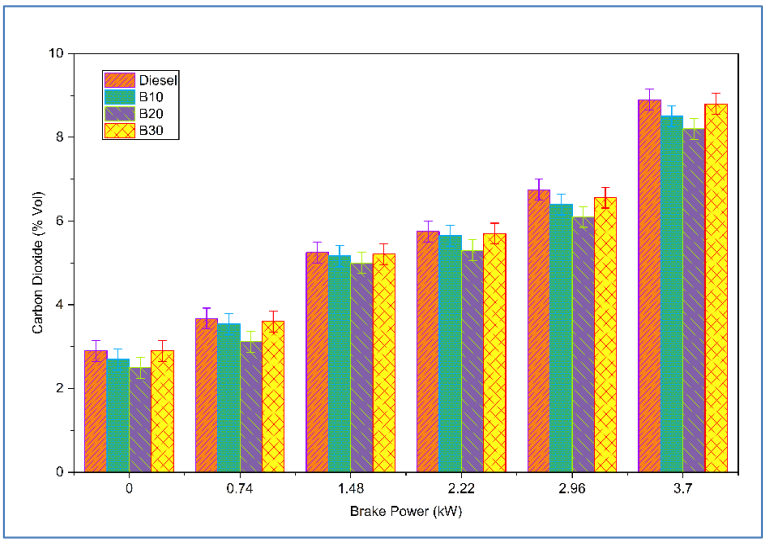

Figure 6. Brake power vs Carbon Dioxide.

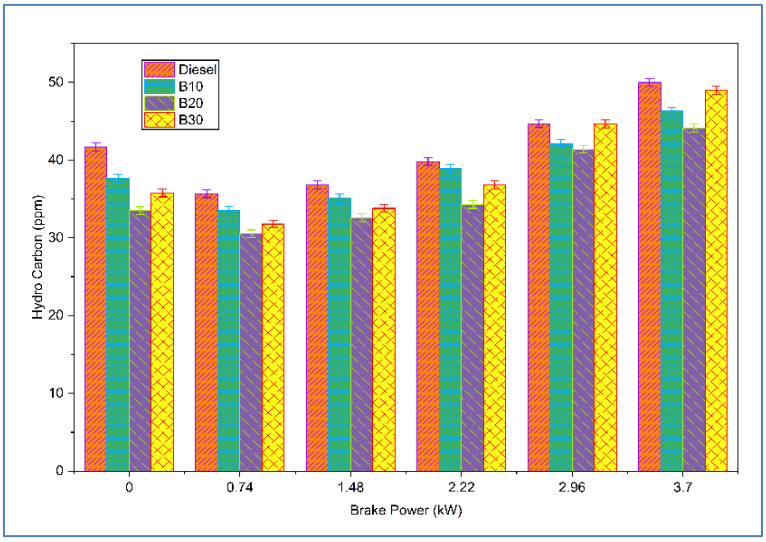

Figure 7. Brake power vs Hydro Carbon.

It observed from the Figure 7, B20 blend has the lower amount of hydro carbon emission for the same operating condition compared to the diesel, B10 and B30. B20 algae bio diesel blend has the accurate amount of oxygen content; it will increase the speed of the combustion process. Because of complete combustion, the un burned hydro carbons level is decreased. So that lower amount of hydro carbon emission releases in the exhaust. For the other samples due to unavailability of oxygen content, some part of the combustion is not completed, so that B10 and B30 algae bio diesel blends have the higher amount of hydro carbon emission. Observation from the graph 8, For the repeated operating conditions, the NOx emissions for algae biodiesel blends has lower amount for B20 compared to B10 and diesel, but may slightly increase and standardize for higher blend as B30 is purely depending on high load engine condition [15]. Increment in NOx emissions in the B20 algae bio diesel blend occurs due to the higher oxygen content present in the biodiesel, it improves speed of the combustion and increases the cylinder pressure and temperature during the combustion process. NOx formation is purely dependent on increase in combustion temperature and additional oxygen, the improved combustion characteristics of B20 creates the reaction between oxygen and nitrogen in the air fuel mixture, produce to higher NOx formation. In B10, the biodiesel having oxygen content availability are lower, resulting combustion temperature is lower and produces the lower NOx emissions compared to B20. From the Figure 9, for the same operating condition B20 *Botryococcus braunii* algae bio diesel blend as fuel in the diesel engine, the smoke emission was decreased compare to the diesel, B10 and B30 algae bio diesel blends. The smoke can be increases because of insufficient amount of oxygen present in the combustion process. During the combustion B20 algae biodiesel blend had the accurate oxygen content [16]. On the other increasing blending ratio, the fuel blend has high viscosity and higher density, the B30 blend produces the higher amount of smoke. Finally, compare with the all the results from the research, *Botryococcus braunii* algae bio diesel blend as the fuel for diesel engine, performance characteristics and emissions characteristics of the diesel engine, B20 bio diesel had the optimized performance compare with the Diesel, B10 and B30 algae bio diesel blend.

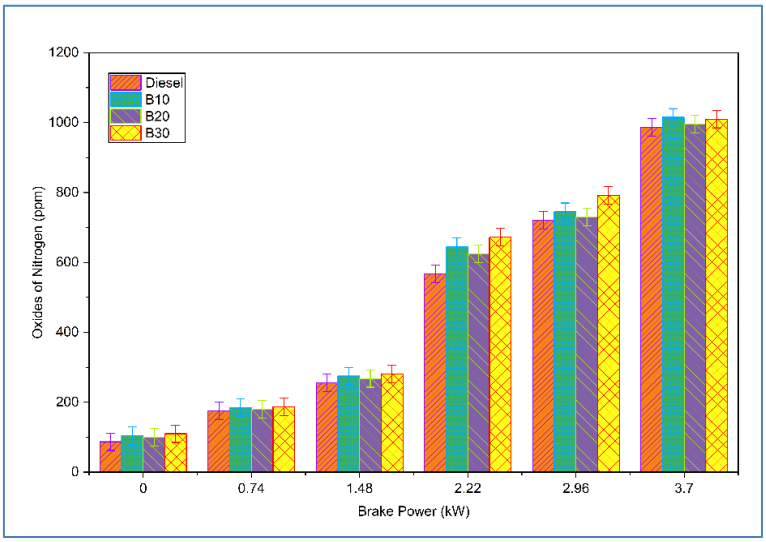

Figure 8. Brake power vs Oxides of Hydrogen.

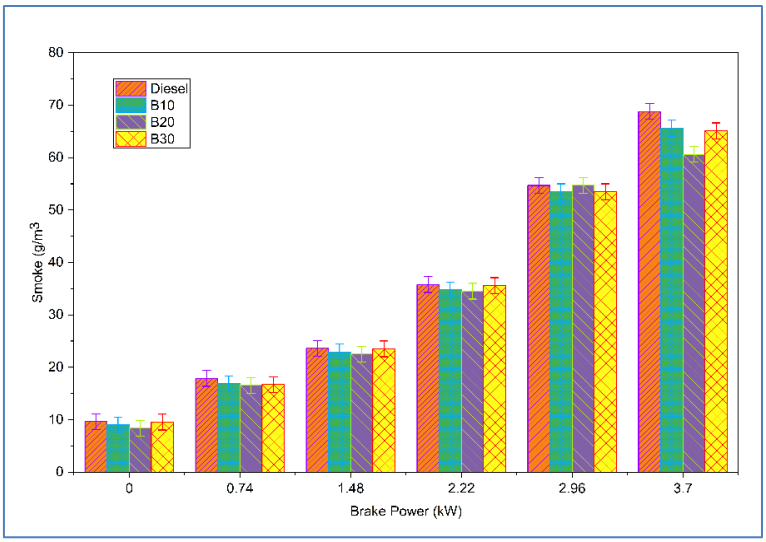

Figure 9. Brake power vs Smoke.

Impact of the Bio Diesel Blended with Nano Curcumin Additives

The curcumin nano additives having the chemical component to improve the fuel combustion while adding with the algae bio diesel blend. Here already identified with the various algae bio diesel blend B20 had the high performance and optimized oxygen content to improve the performance characteristics and emission characteristics of the diesel engine [12]. So various types of the curcumin nano particle blend 25ppm, 50ppm, 75ppm and 100ppm mixed with the B20 algae bio diesel blend and complete the experiment for the same condition with the fuel of B20 with the 4 different types of the nano curcumin additives. Observation from the Figure 10, curcumin nano additives are mixed with the various levels of 25ppm, 50ppm, 75ppm and 100ppm with the one litre of B20 algae bio diesel blend with air tight containers. These are used as fuels for the single cylinder four stroke water cooled engine to attain the increment in the brake thermal efficiency of the diesel engine. When the minimum concentration of the nano additives added in the bio diesel blend having slight increment in the brake thermal efficiency of the engine. If the slight increment in the nano additives the excessive nano particle affected the algae bio diesel, so that the efficiency of the engine is decreased. The nano additives increase the performance of the combustion process and also act as the catalytic for increase the brake thermal efficiency. The curcumin nano particle additives had the oxygen bearing function group, it will supply the oxygen content to the combustion process, this extra oxygen motivate the

combustion process speed, finally the brake thermal efficiency has been increased.

Apparent form the Figure 11, *Botryococcus braunii* algae bio diesel blend B20 with various samples of curcumin nano additives consider as test sample to run the engine, B20 with the 50ppm curcumin nano additives taken as the fuel as given the decrement in the carbon monoxide emission compare with without adding the nano additive B20 algae bio diesel blend, B20 with 25ppm, 75ppm, 100 ppm. Because of the curcumin contains the oxygen to stimulate the combustion process with supplying the additional oxygen to increase the combustion process. Here incomplete combustion has been reduced the carbon monoxide level also decreased. Increment in the level of nano additives increases the excess oxygen content in the combustion process, the excess oxygen does not burn in the combustion chamber, so that the carbon monoxide emission had increased in the diesel engine. In the same operating condition referred from the Figure 12, B20 algae bio diesel blend mixed with the 50-ppm curcumin nano additives attained the lower carbon monoxide emission compare with the without adding nano additives, 25ppm,75ppm and 100pmm added nano additives. Moreover, certainly compare with the 50ppm and 75ppm, 50ppm ha the accurate oxygen content and act as the catalyst for improve the combustion process. Because of the improved combustion efficiency, engine can produce the required power, so that the carbon dioxide releases in lower amount in the exhaust. In addition, the nano sized particles of curcumin improving the evaporation, atomization and mixing in the fuel during the combustion process.

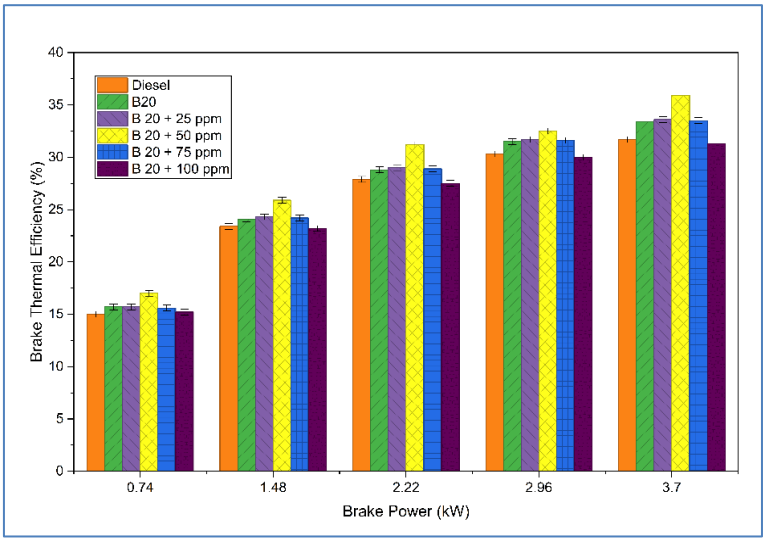

Figure 10. Brake power vs Brake Thermal Efficiency.

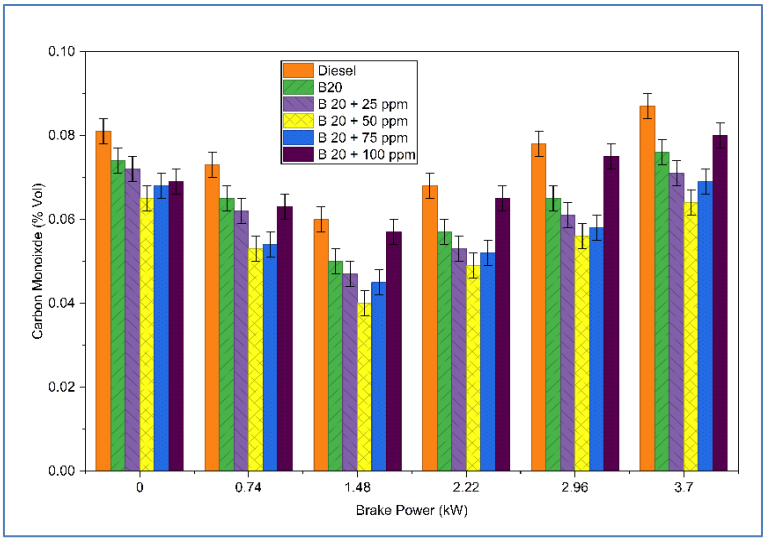

Figure 11. Brake power vs Carbon Monoxide.

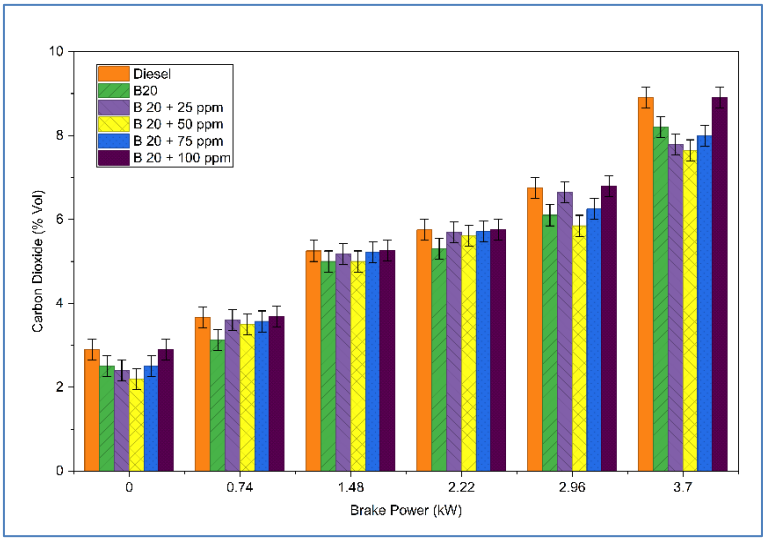

Figure 12. Brake power vs Carbon Dioxide.

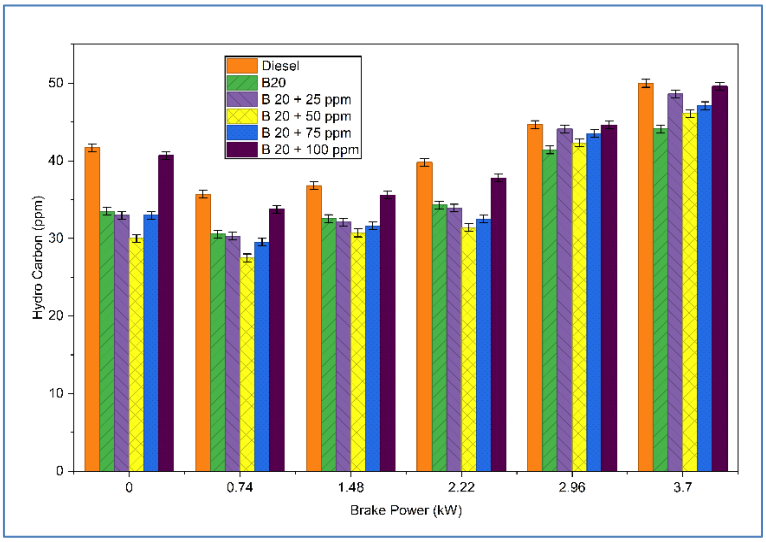

Figure 13. Brake power vs Hydro Carbon.

Under the same identical conditions of engine from the Figure 13, the B20 fuel blended with 50 ppm curcumin nanoparticle had hydrocarbon emissions is lower than B20 without curcumin nano additives. Hydro carbon emissions are generated where the portion of the fuel is balance to unburned due to incomplete combustion process in the cylinder. 50 ppm curcumin nanoparticles added with the B20 algae bio diesel blend improves the combustion performance of the engine by developing the evaporation rate, mixing of fuel and fuel spray quality. particles are in the nano size in range, they improve very high surface area, it helps the combustion reaction very smooth manner. Curcumin nanoparticles with B20 blend exhibit slower catalytic properties, reduces ignition delay and promote a quicker and smoother combustion effect. Because of these effects, the B20 blend with 50 ppm curcumin nanoparticles releases lower unburned HC, with improved combustion efficiency. From the observation of Figure 14, the small size of the curcumin nano particles is producing lower level of oxides of nitrogen during high load condition in the single cylinder four stroke water cooled diesel engine. Most of researchers fails to attain the lower emission of oxides of nitrogen while using algae the bio diesel blend, but here adding the optimized amount of curcumin nano additives to the oxygenated fuel it helps to reduce the human affect most dangerous emission named as oxides of nitrogen. In this nano additive had the excessive amount of the oxygen will helps the increment in the speed of the combustion process. In the combustion process all the

area of the cylinder covered by the oxygen to attain the complete combustion. The cylinder temperature had been increases while adding the more amount of curcumin nano additives with B20 algae bio diesel fuel, it produces the high amount of nitrogen oxide emission during the combustion process. So that the optimized amount of 50ppm nano additive mixed with the B20 algae bio diesel blend had the lower amount of nitrogen oxides during the high load condition of the diesel engine.

Observation from the Figure 15, for the engine identical load condition the algae bio diesel B20 blend added with the 50-ppm curcumin nano additives used as fuel had lower amount of smoke during the exhaust process compare with the without adding the nano additives, 25ppm, 75ppm and 100ppm conditions. B20 algae biodiesel blend mixed with the 50ppm curcumin nano additives fuel contain the excess amount of oxygen it improves the combustion characteristics. Where the incomplete combustion presents because of insufficient oxygen produce the higher smoke emission. The small size nano particle produces the excess amount of oxygen and act as a catalyst the combustion process is rapidly completed without any hesitation. Most of the researched used the bio diesel blends as fuel whether the NOx increases the smoke reduced on other hand NOx is reduced the smoke increases, the both are inversely proposition. Here using the hydroxyl (–OH) and carbonyl (C=O) bonding will reduce the both exhaust emissions simultaneously.

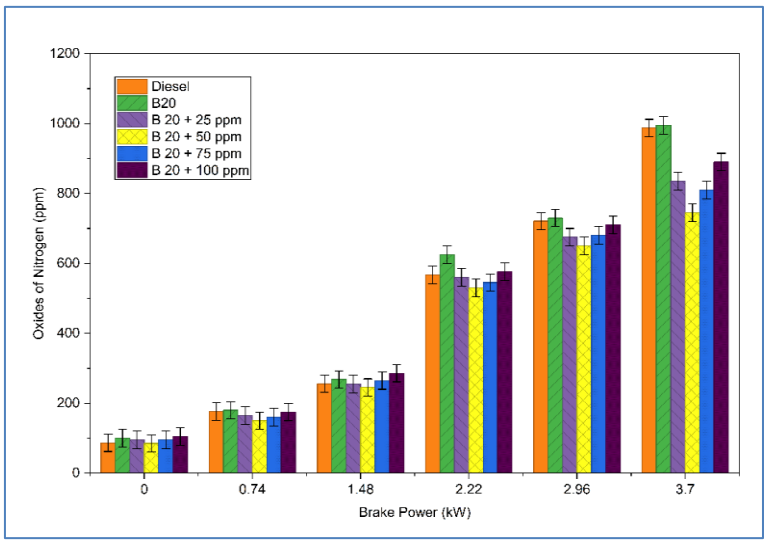

Figure 14. Brake power vs Oxides of Nitrogen (NOx).

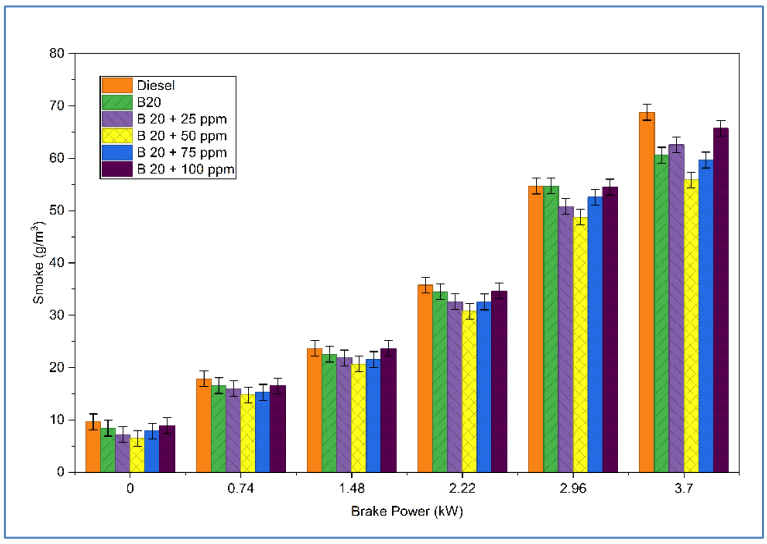

Figure 15. Brake power vs Smoke.

CONCLUSION

This study investigates the performance characteristics and emission characteristics of single cylinder four stroke compression ignition diesel engine fuelled with *Botryococcus braunii* micro algae bio diesel blend as the samples of B10, B20 and B30 with the pure diesel. Using these three types of fuel the performance and emission characteristics are analyzed with minimum to maximum load condition with the eddy current dynamo meter. The experimental results show that among the three types of blends B20 will attain the maximum brake thermal efficiency at the higher-level load condition. The emission characteristics also reduced compare with the B10 and B20 blend of algae bio diesel. Using the *Botryococcus braunii* micro algae bio diesel blend as B20, the compression ignition engine attained the 4.5% of brake thermal efficiency compare with the B10 and B20 bio diesel blend. The exhaust emission for the diesel engine CO, CO_2, HC and smoke was reduced to as 2.7%, 3.5%, 4.7%. and 9.54% respectively. But NOx was slightly increased compared to the pure diesel. To attained the improved combustion characteristics and emission characteristics curcumin nano particles were mixed with B20 bio diesel blend. The curcumin nano particle was added to the blend with four different concentrations like 25ppm, 50ppm, 75ppm and 100ppm. Among the different concentration B20 bio diesel mixed with the 50ppm curcumin nano particle additive fuel blend showed the most favorable results. Many of the researchers are failed to achieve the lower oxides of nitrogen emission using the bio diesel fuel as blend. Added the nano sized particle of curcumin used to attain the complete combustion and act as catalyst during the combustion process. B20 algae bio diesel with 50ppm curcumin nano additives helps to achieve the complete combustion with the brake thermal efficiency increases 6.4% compare to the other samples. For the exhaust emission, B20 algae bio diesel with 50ppm curcumin nano additives helps to attain the minimize the emission like carbon monoxide, carbon dioxide, hydro carbon, Oxides of Nitrogen and smoke decreases 3.2%, 4.2%, 5.3%, 8.34% and 7.23% respectively for the diesel engine without required any engine modifications.

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