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An Experimental Assessment on the Impact of Injection Pressure on the Characteristics of a Diesel Engine Powered with the Blend of Diesel and Microalgae Biodiesel

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Abstract*: *Microalgae was recognized as the sustainable energy feedstock for producing biofuels. Now bio-diesel produced from algal biomass is getting ready to address the energy crisis that the world would face tomorrow. This paper deals with the utilization of microalgae biodiesel at 30% blend, to investigate the influence of operating parameter such as injection pressure on the characteristics of a compression ignition engine. Microalgae crude oil was derived from chlorella vulgaries and it was converted into microalgae methyl ester (MME) using transesterification process. The desired test fuel was prepared by mixing of 30% MME with 70% pure diesel and designated as B30. The experiment was performed on a single four-stroke cylinder diesel engine powered with B30 at various fuel injection pressures 180 bar range, 200 bar and 220 bar range. The experimental findings showed that there was no important effect on BSFC from altered injection pressures, while BTE was increased at 200 bar by a maximum of 14.09 percent. At 200 bar injection pressure, exhaust emissions such as CO, CO2, UHC and smoke opacity were enhanced mostly, but NOX emissions were reduced, and increases in cylinder peak pressure were only discovered at 200 bar.

Keywords*: *Sustainable energy, Chlorella Vulgaries, Microalgae crude oil, Microalgae methyl ester, Transesterification

I. INTRODUCTION

Renewable energy is a reassuring alternative source soon because it leaves the environment clean and safe, as it does not produce large amounts of green house gas emissions. It revitalizes the economy of the country by increasing demand and prices of the agricultural products and reduces the dependence on the fossil fuels. It is expected by 2040 that, half of the global energy demand will be accomplished only by renewable sources [1]. Biomass is currently the most promising source of renewable energy that will continue in the future. It has been assessed that, at the present pace of consumption, conventional fuel resources will be depleted within 50 years[2]. Biodiesel is presently made from vegetable and animal oils, but not from microalgae. Biodiesel is a proven fuel, biodiesel production and use technology has been known for more than 50 years [3]. Anoop Singh et al. [4] have reported that, third generation

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The apparent response to this is biofuels from algal cells cult ivated on non-arable soil food–fuel competition. A.L. Ahmad et al. [5] stated that, Biodiesel resources should focus on feed stocks that do not compete with food crops, Do not result in land clearing and reductions in greenhouse g ases. Microalgae were theoretically shown to be a potential source to produce third generation bio-diesel. Teresa M. Mata et al. [6] expressed that, many companies are claiming that they are at the frontline of the technology and will be producing algal biodiesel economically within the next few years.

Microalgae are prokaryotic or eukaryotic photosynthetic mic roorganisms that are able to grow rapidly and live under hars h conditions because of their single or simple multicellular structure. Examples of prokaryotic microorganisms are Cyanobacteria (Cyanophyceae) and eukaryotic microorganisms are green algae (Chlorophyta) and diatoms (Bacillariophyta) [7]. Microalgae can supply renewable biofuels of several kinds. These include methane generated by algal biomass anaerobic digestion. The concept of using microalgae as a fuel source is not new, but it is now being taken seriously because of the rising petroleum price and, more substantially, the growing concern about global warming associated with fossil fuel burning [8]. Yusuf Chisti noticed that biodiesel Microalgae appear to be the only renewable biofuel capable of completely displacing petroleum-derived transport fuels w ithout adversely affecting food supplies and other crop prod ucts [9]. M.A. Rahman et al. [10] produced biodiesel from microalgae spirulina maxima by employing two step esterification processes. Ayhan Demibras et al. [11] stated that, The world's fastest increasing crops are microalgae. The growth rate of microalgae is much quicker than terrestrial plants. Approximately 50% of their weight is oil. For vehicles, trucks and aircraft, this lipid oil can be used to create biodiesel. As easily as petroleum obtained from land-based plants, algal-oil procedures into biodiesel. The impact of algal biodiesel on diesel engine performance and emission features was explored by Farouk K. El-Baz et al.[12]. The result showed that, biodiesel produced from algae is environmentally friendly.

Saddam H. AI-Iwayzy et al. [13] conducted an experiment on single cylinder diesel engine using microalgae oil blended with diesel, and results indicated that, the engine emissions such as NO_X, CO, CO_2 and HC were reduced with 20% of blend. Ganesh Nagane et al. [14] tested the variable compression

Diesel engine ratio fuelled by biodiesel algae and diesel mixt ures. The experimental results revealed that, emission characteristics like CO, CO_2 decreased whereas NO_X Increased as the mixing percentage improved. J. Kuberan et al.[15] conducted a single-cylinder diesel engine experiment powered with Spirulina algae biodiesel and fossil diesel blends. At the end it was concluded that, spirulina algae biodiesel S30 has produced best emission characteristics than pure diesel. Karthikeyan et al. [16] have investigated the environmental effect of Microalgae Methyl Ester used as alternate fuel blended with diesel in a compression ignition engine. The experimental findings show that the use of biodiesel microalgae with nano additives in diesel engines has shown excellent efficiency improvements and reduction in exhaust emissions [16].

Ranjan Kumar Bhaogobaty [17] had announced that, endophyte a fungal microorganism has the ability to produce biofuel and represents a promising source of new biofuel in future. Ramon Piloto-Rodriguez et al. [18] delineated that, the effect on diesel engines of the use of biofuels generated by microalgae. Biofuels derived from algae can have the lower impact on the environment and the food supply than biofuels produced from crops. Raphael slade et al. [19] have examined three aspects of microalgae, energy and Balance of carbon, environmental effects and manufacturing costs,and they have discussed several parameters which influences the production cost of biofuels especially algal biofuels. At the end they have found that, biofuels derived from algal biomass have a role to play in near future. James W. Richardson et al. [20] have carried out a financial assessment on the two different cultivation systems for algae biomass and biofuel production in the microalgae industry, one is open raceway ponds (ORPs) and another one is closed photobioreactors (PBRs). This assessment was concluded that, the PBR cultivation system has a significantly lower risk of production and total cost per gallon oil will be lower than ORP and also, they have emphasized that biofuels from microalgae to be an economically viable industry.

N. Charyulu T et al. [21] A single cylinder direct injection water-cooled diesel engine was tested with diesel and microalgae (Chlorella Vulgaries) methyl ester blends and found that, 30% blend produced better performance, emission and combustion Results from pure diesel. Gokhan Tuccar et al. [22] have carried out an Diesel engine experimental investigation using diesel and microalgae biodiesel blends with the volumetric ratio of 5%, 10%, 20% and 50Their percentage, while efficiency parameters such as torque and brake power are lowered, showed their outcomes. the emission parameters like CO and NOx were improved using microalgae biodiesel. Violeta Makarevicience et al. [23] have undergone a test on VALMET 320 DMG diesel generator with petrol mixtures of 30% algae methyl ester and 30% Rapeseed methyl ester with 70% fossil diesel. After the results are analyzed and compared, the exhaust emissions are 10% lower for B30RME compared to B30AME. Saddam H. Iwayzy, and Talal Yusaf [24] have tested the diesel engine for change of its characteristics while the engine powered with 100% microalgae biodiesel from chlorella protothecoides (MCP-B100) as alternative fuel, the results showed that, MCP-B100 produced less emissions compared to pure diesel. Muhammad Aminul Islam et al. [25] have reviewed the significance of microalgae biodiesel in the future to reduce the exhaust emissions from diesel engines, they have written that, biodiesel contains 10-15% of oxygen by mass while the pure diesel is almost null of oxygen. P. Mohamed Shameer et al. [26] have gone through a review on several researches on The impact of operating parameters such as injection pressure and engine injection timing emission characteristics and they have discussed the appropriate causes for the deviation of emission characteristics.

Chlorella vulgaris is green eukaryotic microalgae possessing the potential to be used as feed stock for producing biofuel. It can be treated as a good alternative to the current biofuel crops such as soybean, rapeseed etc., as it is more productive and do not compete with food products [4]. It can produce large amount of lipid content, up to 20 times more than crop [27]. It contains lipids 5-40% of the dry mass [28]. And also, it contains more quantity of starch which is good enough to produce bio-ethanol. However, biodiesel produced from micro algae is still far from being competitive with fossil fuels due to their high production cost [29]. It is a spherical in shape About 2 to 10 μm in diameter, only carbon dioxide, water, sunlight and a tiny amount of sunlight are required for breeding amount of minerals [30]. Yusuf Chisti reported that, there are three main sources of microalgae (Chlorella sp, Spirulina sp, and Nitzschia sp). The oil contents of these three main sources are 28-32%, 50-77% and 45-47% respectively [8].

The present experimental study was dealt with the Single cylinder four-stroke diesel engine features fueled with the blend of 30% microalgae methyl ester and 70% petroleum diesel under the influence of various injection pressures. The engine was run at constant speed with varying load conditions, during the test the performance parameters (BSFC, BTE), emission parameters (EGT, CO_2, CO, UHC, NO_X and smoke) and combustion parameters (Peak pressure of the cylinder, Max. Rate of heat release, delay of ignition) were measured, evaluated, and discussed.

II. MATERIALS AND METHODS

A. Bio-Diesel Preparation

Microalgae crude oil was purchases from oil producers and it was Converted by trans ester into methyl ester microalgae. 1000 ml of raw microalgae oil is drawn in a round bottom flask during trans esterification. 12 grams of alkaline KOH and 250 ml of methanol in a distinct beaker and stirred until KOH is completely dissolved in methanol. Round bottom flask with raw oil is heated with continuous stirring to 60^0C, after ensuring the required temperature, KOH-Methanol solution is poured into raw oil. Oil-KOH-Methanol solution is stirred at 720 rpm for two hours at temperature 60^0C, then after transfer the solution into another vessel and allow it to cool till two layers are formed. Top layer is microalgae biodiesel and bottom layer is glycerine, both are separated, then the biodiesel is subjected to repeated water washings till ensuring no glycerine present in the Biodiesel is then heated to 1000C for a while to remove water particles associated with MME, now it is preserved for its usage as biodiesel in diesel engine. The physico-chemical properties of microalgae methyl ester were measured at ITA labs, Chennai and they are tabulated in the table 1. The required test sample for this research work was prepared by mixing 30% of microalgae methyl ester and 70% of fossil diesel (MME30D70) and this test sample was designated as B30.

Table: 1. Physico-chemical Properties of Microalgae Biodiesel[21]

Fuel Property	Biodiesel ASTM(D6751	Diesel Fuel ASTM(D975	MME
Density (Kg /m^3)	860 - 900	820 - 860	876
Cetane Number	Min.47	40 - 55	46
Calorific Value	---	42000-46000	38945
Kinematic Viscosity @ 40^0C (mm^2/S)	1.9 – 6.0	2.6 – 5.7	5.32
Flash Point (^{0}C)	Min.130	60 - 80	178

B. Experimental Setup

Fig.1Photographic view of experimental setup

A single cylinder four-stroke diesel engine has been tested to assess the performance, emission and combustion features of B30 and fossil diesel mixtures at different injection pressures. The tested engine was TV 1 Model engine from Kirloskar. Fig.1 shows the photographic perspective of the experimental configuration. The engine is combined with the eddy current dynamometer, the AVL 444 N five gas analyzer and the AVL smoke meter to assess levels of emissions. The pressure sensor, TDC encoder and computer-escorted data acquisition chord are given to evaluate the combustion parameters. Table 2 shows the requirements of the experimental test rig.

Table 2. Specifications of the Test Rig[21]

Make	Kirloskar
Model	TV 1
Type	Single cylinder, four stroke, vertical diesel engine
Rated Speed	1500 rpm
Cylinder bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5 : 1
Cylinder bore	87.5 mm
Stroke	110 mm
Stroke	110 mm
Compression ratio	17.5 : 1
Loading	Eddy current dynamometer
Cooling	Water cooling

C. Experimental Procedure

Firstly, allow the engine to run with pure diesel at rated speed (1500 rpm) for few minutes, and then vary the load from zero to full load in steps (0, 25%, 50%, 75% and 100%) note down the readings of performance, emission and combustion parameters at each load. Now power the engine with B30 and repeat the experiment 180 bar, 200 bar and 220 bar at different injection pressures and register the parameters as above. Finally, the experimental results were analyzed and discussed.

III. RESULTS AND DISCUSSION

A. Characteristics of Performance

Fig.2 shows the variation in brake-specific fuel consumption (BSFC) for diesel and test sample B30. The BSFC is used to show engine combustion efficiency and fuel economy, as the graph shows bsfc reduced for all injection pressures with bp rise. This is primarily owing to the improvement of combustion by elevated in-cylinder temperature at greater motor loads. The findings indicated that the BSFC is nearly the same with a small deviation of 0.01Kg / Kw-h at all injection pressures at complete load condition. Diesel enrolled at 180 bar min. bsfc and B30 registered at 200 bar min. bsfc.

Fig.3 demonstrates the brake thermal efficiency (BTE) variation for both fuels with regard to brake energy. Overall, BTE improves with BP rise owing to the low energy input requirement for greater energy output at a specified load as heat loss at greater loads is decreased. It was observed that, because of the wealthy oxygen content in biodiesel, BTE of B30 is much better than pure diesel for all injection pressures.

It was also recognized at complete load, with a greater heat brake effectiveness at 180 bar and 220 bar than standard. injection pressure of 200 bar, whereas B30 has showed greater thermal efficiency at every injection pressure than that of pure diesel. B30 has reported maximum thermal efficiency at 200 bar and is increased by 14.09% while compared to fossil diesel.

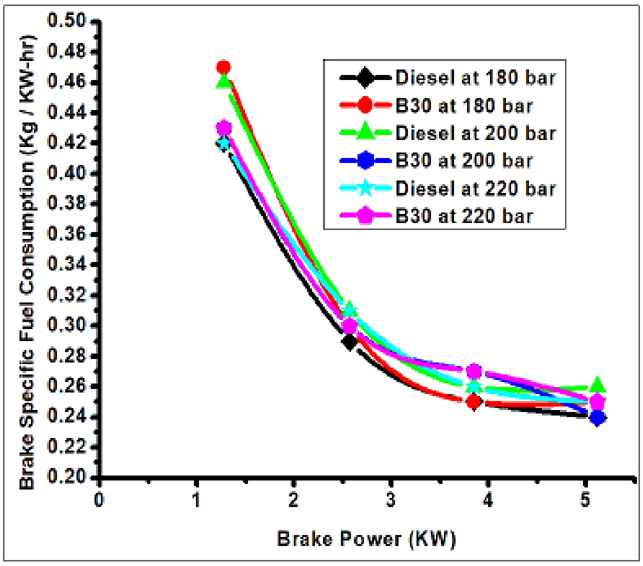

Fig.2 Variation of BSFC with BP

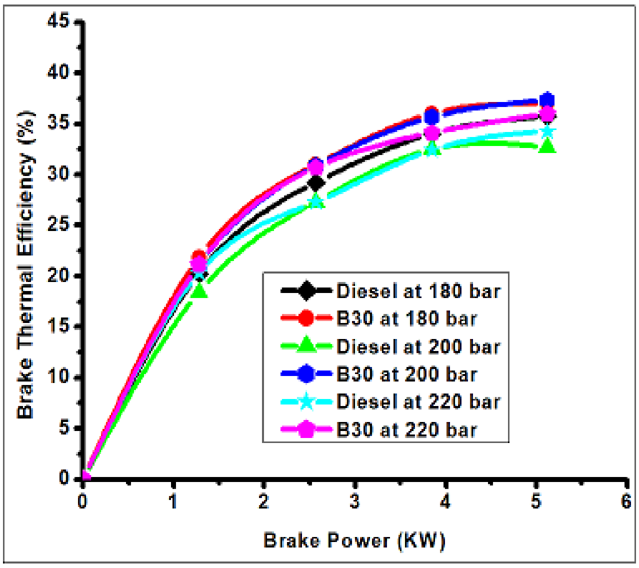

Fig.3 Variation of BTE with BP

B. Characteristics of Emission

Fig.4 communicates the relationship between Temperature of exhaust gas (EGT) and brake energy at all injection pressures for both pure diesel and B30. Temperature of exhaust gas and brake energy are inversely proportional to each other as big quantities of heat are wasted by exhaust. The outcome showed that, for all loads, the EGT of B30 is lower than that of petrol at all fuel pressures. It was noted at complete load condition that the distinction is very big at 200 bar compared to standard diesel fuel and is decreased by 12.79 percent.

Fig.5 shows the variation in the emission of carbon dioxide (CO2) with brake energy for tested fuels. As the strength of the brake rises, the CO2 percentage improves. Faster movement of the fuel particles at higher injection pressures resulting in rapid vapourization causing increase in CO2, this is the principal by product of efficient combustion. It was observed that, the percentage of CO2 discharged by the engine with B30 is more than that of diesel at 180 bar and 220 bar, but at 200 bar it is reduced by 2.71% as compared to pure diesel at full load condition.

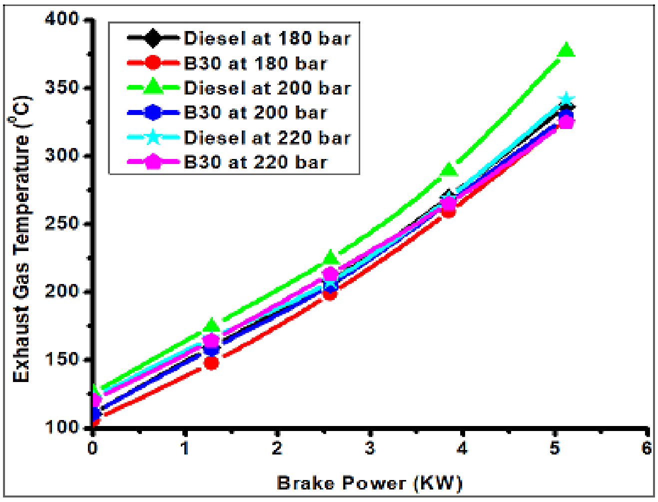

Fig.4 Variation of EGT with BP

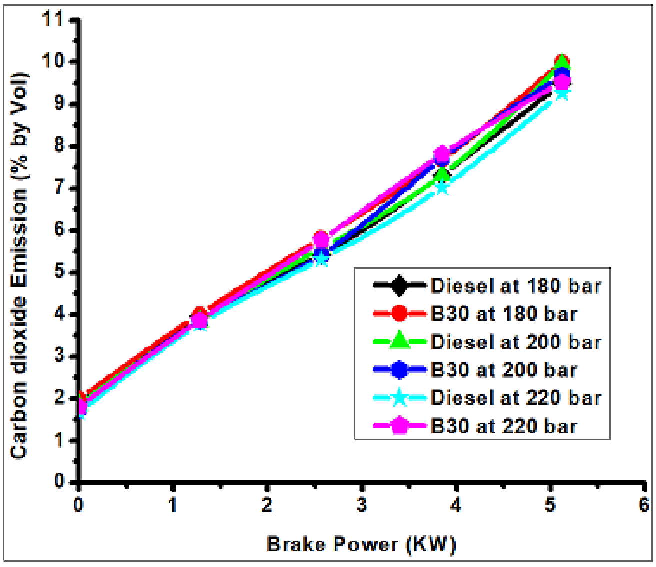

Fig.5 Variation of CO_2 Emission with BP

Fig.6 shows the disparity of carbon monoxide (CO) emissions at distinct injection pressures with brake force for pure diesel and B30. In reality, CO emissions are growing as the load increases. Rich fuel-air mixture is burned as the load rises, thus forming more CO owing to oxygen shortages. The findings showed that the proportion of CO for B30 is higher than that of diesel fuel at all injection pressures from zero load to 75 percent load, but at complete load, the CO proportion is decreased by 4.5 percent at 180 bar, decreased by 71.97 percent at 200 bar and by 220 bar no.reduction was found compared to fossil diesel

Fig.7 demonstrates the emission deviation of unburned hydrocarbon (UHC) and increased brake power. Based on the outcomes of the experiment, the percentages of hydrocarbon are gradually risen from zero to complete load. At higher injection pressures fuel droplets move with high velocity resulting in improper mixing with air leads to high HC content. While comparing B30 with diesel it was found that, the amount of UHC for B30 is less than diesel only at 200 bar, but surprisingly at 180 bar and 220 bar UHC emission is more for B30 than diesel. It was decreased by 15.56% at complete load and 200 bar compared to pure petrol.

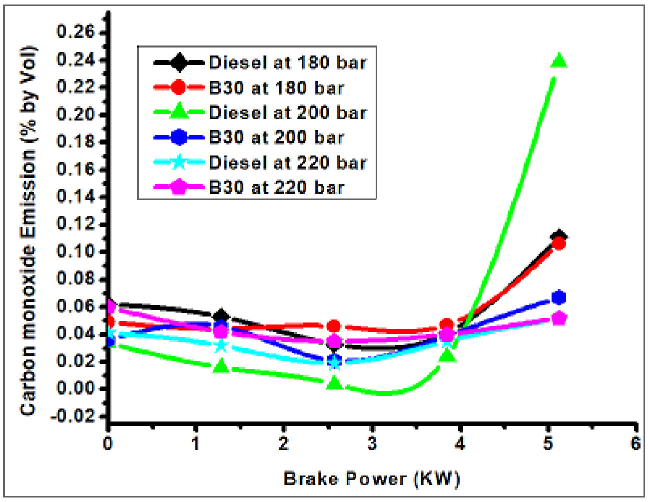

Fig.6 Variation of CO Emission with BP

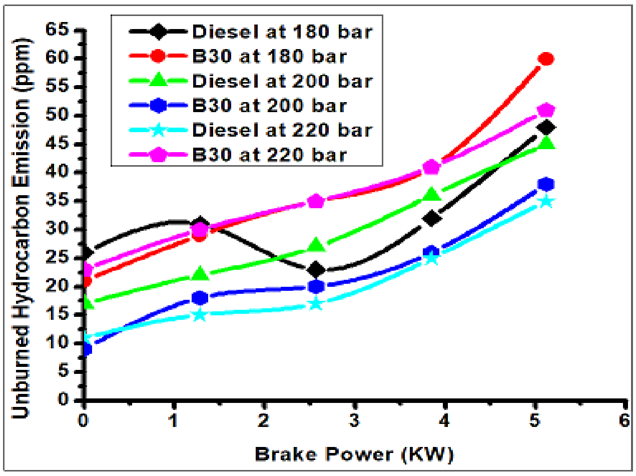

Fig.7 Variation of UHC Emission with BP

Fig.8 illustrates the variation in the emission of nitrogen oxides (NOX) in brake energy. In popular practice, nitrogen can respond with oxygen to form nitrogen oxides owing to elevated cylinder pressure and temperature. Biodiesel can therefore generate more NOX than diesel fuel because it includes a elevated content of oxygen. Based on the information, it was discovered that, for all injection pressures, the trend was only continued at 220 bar at original load circumstances from 0 to 50 percent load NOX emission of B30 was lower than diesel, but from 75 percent to 100 percent load, but it was increased at 180 bar and 200 bar compared to diesel. It risen by 10.26% and 13.09% respectively at 180 bar and 200 bar, but at 220 bar it was slightly decreased by 0.64% compared to conventional diesel.

Fig.9 reports the smoke opacity variation with brake strength for the fuel being tested. With enhanced brake energy at all injection pressures, smoke opacity gradually improved. For all injection pressures B30 has claimed more percentages of smoke opacity than petroleum diesel for all the loads. Smoke opacity is the particulate matter resulting from partially burning of the fuel due to poor atomization of high viscous fuels. Fuel atomization can be improved by increasing injection pressure. But the results revealed that, only at full load condition and at 200 bar B30 has produced less percentage of smoke than diesel by 10.36%.

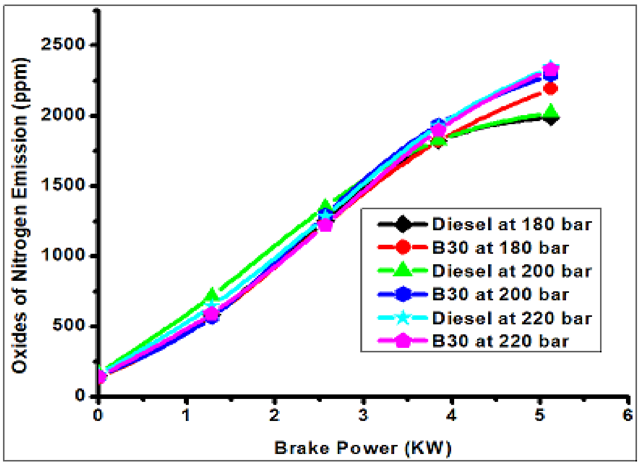

Fig.8 Variation of NO_X Emission with BP

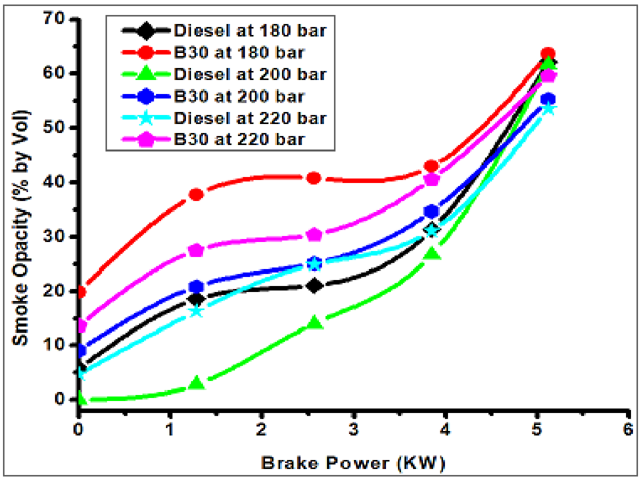

Fig.9 Variation of Smoke Opacity with BP

C. Characteristics of Combustion

Fig.10 represents the change Cylinder maximum brake pressure for both fuels at different injection pressures. From the graph it was observed that with an rise in brake force, the cylinder peak stress rises continuously. The maximum pressure generally determines the amount of fuel burned in the premixed combustion stage in turn regulated by the delay of the ignition.

The cylinder peak pressure was gradually risen from zero load to complete load for all injection pressures. The outcome was recorded at complete load at 180 bar and 220 bar the peak pressure was Simply reduced by 0.47% and 0.22% respectively, but the peak pressure of B30 at 200 bar is higher than that of diesel fuel by 2.66%.

The relationship between maximum heat release rate (Max. HRR) and brake power is shown in Fig.11. The maximum heat release rate of biodiesel is lower than that of fossil diesel for all injection pressures. This is due to poor atomization of spray due to high viscosity of biodiesel. Condition of complete load, max. The B30 heat release rate decreased by 22.11% at 180 bar, by 11.70% at 200 bar and by 21.33% at 220 bar compared to pure diesel.

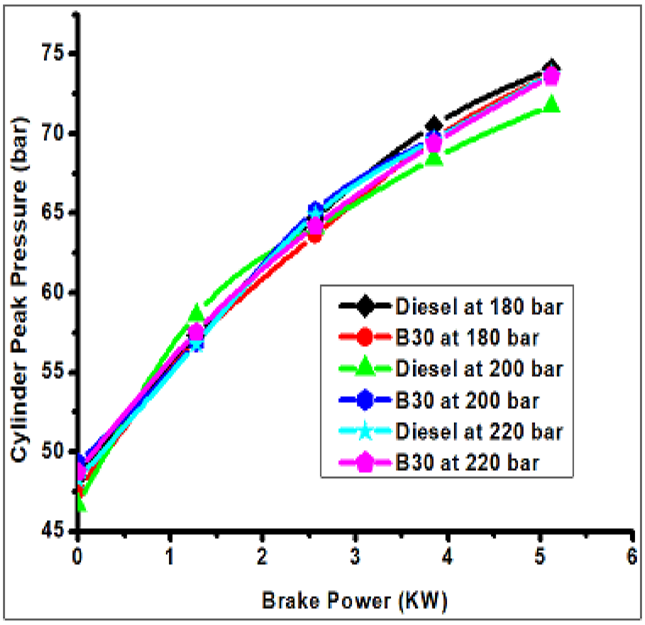

Fig.10 Variation of Cylinder Peak with BP

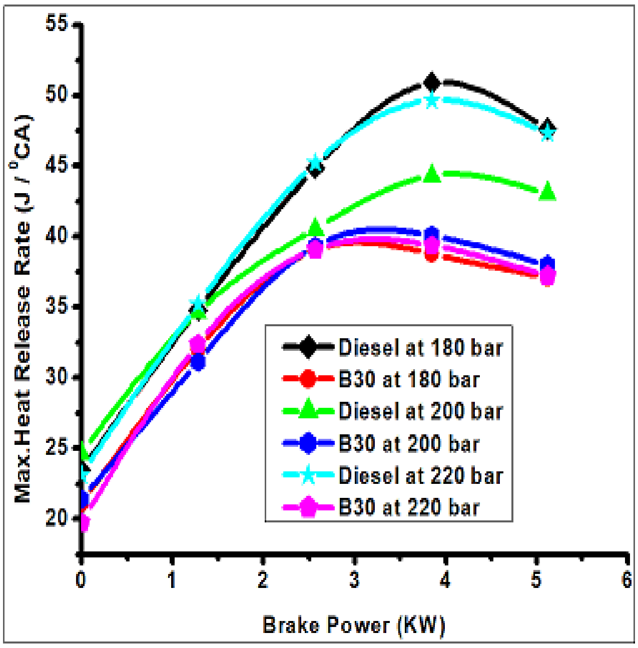

Fig.11 Variation of Max. H.R.R with BP

Fig.12 shows the variety of the ignition delay with petroleum diesel and B30 brake energy at different injection pressures. Ignition delay could be the important parameter at the beginning of combustion, it can be measured as a time The interval between the beginning of the fuel injection and the begin of the crank angle (CAD) fuel burning. The maximum peak pressure within the cylinder is dependent on the delay in ignition. It was observed from the experimental data that for all injection pressures, the ignition delay was constantly reduced with a one-degree variation from zero load to full load.

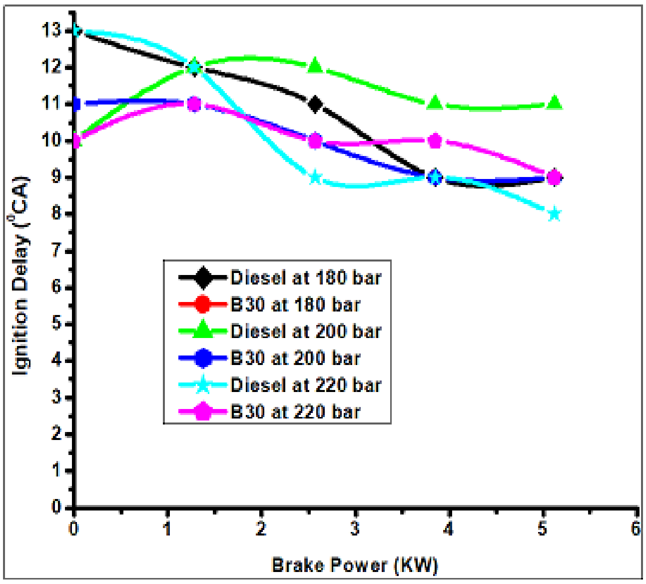

Fig.12 Variation of Ignition Delay with BP

IV. CONCLUSIONS

A single cylinder diesel engine powered by pure diesel and B30 was effectively tested and the findings analyzed and discussed, hence the following conclusions are narrated based on the above evaluation at full load condition,

1. For all injection pressures, the BSFC of pure diesel and B30 are almost similar with a small deviation of 0.01 Kg / Kw-hr. Minimum bsfc has been recorded at 200 bar B30 compared to fossil diesel.
2. B30's BTE was risen to 200 bar injection pressure, then slightly reduced at 220 bar. Compared to pure diesel, BTE risen by 14.08 percent at 200 bar.
3. There was a fluctuation in the measurement of EGT for altered 180 bar, 200 bar and 220 bar injection pressures with a temperature difference of 20c, no trend was discovered.
4. Compared to standard diesel, the proportion of CO2 emissions was reduced with greater injection pressure for B30.
5. The B30 CO concentration was followed with greater injection pressure downward trend. It was discovered that, compared to Pure Diesel at 200 bar, the injection pressure of 220 bar CO concentration was lowered by 78.24 percent.

6. At the 220 bar higher injection, the UHC emission was increased. being reduced up to 200 bar while comparing injection pressures at the range of 180 bar-220 bar, at 200 bar UHC emission was minimum and it is reduced by 15.56% compared to petroleum diesel.
7. The NO_X concentration was followed continuously increasing trend with increasing injection pressures at the range of 180 bar to 220 bar.
8. The smoke opacity was identified with decreasing trend for diesel with a range of injection pressures of 180-200 bar, but for B30 it was fluctuated between 180-220 bar injection pressures. At standard injection pressure of 200 bar it was reduced by 10.36% compared to pure diesel.
9. The peak cylinder pressure was decreased with increased injection pressures from 180 bar to 220 bar and at the same time heat release rates were fluctuated between injection pressures of 180 bar to 200 bar.

Finally, it can be expressed undoubtedly that, B30 exhibited better emission characteristics than pure diesel with modified injection pressures.

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