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

Nambaya Charyulu Tatikonda, P. Naveenchandran

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 vulgarities 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 conducted on single cylinder four stroke diesel engine powered with B30 at various fuel injection pressures in the range of 180 bar, 200 bar and 220 bar. The experimental results showed that, no significant impact of modified injection pressures on BSFC, whereas BTE was increased maximum by 14.09% at 200 bar. The exhaust emissions such as CO, CO₂, UHC and smoke opacity were improved mostly at 200 bar injection pressure, but NOx emission was increased, and increment in cylinder peak pressure was discovered only 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 greenhouse 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]. At this moment biomass is the most promising renewable source that will be continued so in the coming future. It has been measured that, the conventional fuel resources will be depleted within 50 years at the current rate of consumption [2]. Biodiesel is produced currently from plant and animal oils, but not from microalgae. Biodiesel is a proven fuel, the technology for producing and using biodiesel has been known for more than 50 years [3]. Anoop Singh et al. [4] have reported that, third generation biofuels from algal cells grown on non-arable land is the obvious answer to the 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 lead to land clearing and provide greenhouse–gas reductions. Theoretically microalgae have been 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 forefront of the technology and will be producing algal biodiesel economically within the next few years.

Microalgae are prokaryotic or eukaryotic photosynthetic microorganisms that can grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure. Examples of prokaryotic microorganisms are Cyanobacteria (Cyanophyceae) and eukaryotic microorganisms are green algae (Chlorophyta) and diatoms (Bacillariophyta) [7]. Microalgae can provide several types of renewable biofuels. These include methane produced by anaerobic digestion of the algal biomass. The idea of using microalgae as source of fuel is not new, but it is now being taken seriously because of the escalating price of petroleum and, more significantly the emerging concern about global warming that is associated with burning fossil fuels [8]. Yusuf Chisti noticed that biodiesel from microalgae seems to be the only renewable biofuel that has the potential to completely displace petroleum derived transport fuels without adversely affecting supply of food and other crop products [9]. M.A. Rahman et al. [10] produced biodiesel from microalgae spirulina maxima by employing two step esterification processes. Ayhan Dembrass et al. [11] stated that, microalgae are the fastest growing plants in the world. Microalgae have much faster growth-rates than terrestrial crops. About 50% of their weight is oil. This lipid oil can be used to make biodiesel for cars, trucks and airplanes. Algal-oil processes into biodiesel as easily as oil derived from land-based crops. Farouk K. El-Baz et al. [12] investigated the effect of algal biodiesel on the Performance and Emission characteristics of diesel engine. The result showed that, biodiesel produced from algae is environmentally friendly. Saddam H. Al-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 NOx, CO, CO2 and HC were reduced with 20% of blend. Ganesh Nagane et al. [14] tested the variable compression ratio diesel engine fuelled with algae biodiesel and diesel blends. The experimental results revealed that, emission characteristics like CO, CO2 decreased whereas NOx increased with increase in blending ratio. J. Kuberan et al. [15] did experimentation on single cylinder diesel engine 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 results reveal that the use of microalgae biodiesel blend with nano additives in diesel engine has exhibited good improvement in performance characteristics 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 impact of the use of biofuels produced from Microalgae to power diesel engines. 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 carbon balance, environmental impacts and cost of production, 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] have tested a single cylinder direct injection water cooled diesel engine with diesel and microalgae (Chlorella Vulgares) methyl ester blends and found that, 30% blend produced better performance, emission and combustion results than that of pure diesel. Gokhan Tuccar et al. [22] have carried out an experimental investigation on diesel engine using diesel and microalgae biodiesel blends with the volumetric ratio of 5%, 10%, 20% and 50%, their results showed that although the performance parameters such as torque and brake power values are reduced, the emission parameters like CO and NOx were improved using microalgae biodiesel. Violeta Makareviciene et al. [23] have undergone a test on VALMET 320 DMG diesel generator while using fuel blends of 30% algae methyl ester and 30% Rapeseed methyl ester with 70% fossil diesel. After the results are analyzed and compared, it was found that, the exhaust emissions are 10% lower for B30RME compared to B30AME. Saddam H. Iwayzy, and Talal Yusaif [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 influence of operating parameters such as injection pressure and injection timings on the engine 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, for its reproduction it requires only carbon dioxide, water, sunlight and a small amount of minerals [30]. Yusuf Chisti reported that, there are three main sources of microalgae (Chlorella sp, Spirulina sp, and Nitzscha 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 characteristics of single cylinder four stroke diesel engine 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, CO2, CO, UHC, NOx and smoke) and combustion parameters (Cylinder peak pressure, Max. Heat Release Rate, Ignition delay) were measured, evaluated, and discussed.
II. MATERIALS AND METHODS

A. Bio-Diesel Preparation

Microalgal crude oil was purchased from oil producers and it was converted into microalgal methyl ester through transesterification process. During transesterification 1000 ml of raw microalgal oil is taken in a round bottom flask. 12 grams of KOH as alkaline catalyst and 250 ml of methanol taken in a separate beaker and stirred until KOH is completely dissolved in methanol. Round bottom flask with raw oil is heated with continuous stirring to 60°C, 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°C, then after transfer the solution into another vessel and allow it to cool till two layers are formed. Top layer is microalgal 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 then it is heated for a while at 100°C 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 IITA labs, Chennai and they are tabulated in the table 1. The required test sample for this research work was prepared by mixing 30% of microalgal methyl ester and 70% of fossil diesel (MME30D70) and this test sample was designated as B30.

Table 1: Physico-chemical Properties of Microalgae Biodiesel

| Property               | Diesel Fuel | Biodiesel | MME  |
|------------------------|-------------|-----------|------|
| Density (Kg/m³)        | 820-860     | 860-900   | 876  |
| Kinematic Viscosity    | 2.6-5.7     | 1.9-6.0   | 5.32 |
| Flash Point (°C)       | 60-80       | Min.130   | 178  |
| Cetane Number          | 40-55       | Min.47    | 46   |
| Calorific Value (KJ/Kg)| 42000-46000 | ---       | 38945|

B. Experimental Setup

A single cylinder four stroke diesel engine was tested to estimate the performance, emission and combustion characteristics when it is powered with B30 and fossil diesel blends at various injection pressures. The tested engine was TV 1 model Kirloskar engine. The photographic view of experimental setup is shown in fig.1. The engine is coupled to eddy current dynamometer, AVL 444 N five gas analyzer and AVL smoke meter to measure emission concentrations. To measure the combustion parameters, it is provided with pressure sensor, TDC encoder, and data acquisition chord escorted by computer. The specifications of the experimental test rig are shown in the table 2.

Table 2: Specifications of the Test Rig

| Make     | Kirloskar |
|----------|-----------|
| Model    | TV 1      |
| Type     | Single cylinder, four stroke, vertical diesel engine |
| Rated Power | 5.12 KW |
| Rated Speed | 1500 rpm |
| Cylinder bore | 87.5 mm |
| Stroke   | 110 mm    |
| Compression ratio | 17.5 : 1 |
| Cooling  | Water cooling |
| Loading  | Eddy current dynamometer |

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 at various injection pressures 180 bar, 200 bar and 220 bar and register the parameters as above. Finally, the experimental results were analyzed and discussed.

III. RESULTS AND DISCUSSION

A. Characteristics of Performance

Fig.2 represents the variation of brake specific fuel consumption (BSFC) with brake power (BP) for diesel and test sample B30. The BSFC is used to indicate the efficiency of engine combustion and fuel economy, as the graph indicates bsfc decreased with increase in bp for all injection pressures. This is mainly due to at higher engine loads the combustion is improved by high in-cylinder temperature. The results revealed that at full load condition, the BSFC at all injection pressures is almost same with little deviation of 0.01Kg/Kw-h. Diesel has registered min. bsfc at 180 bar and B30 has registered min. bsfc at 200 bar.

Fig.3 shows the variation of brake thermal efficiency (BTE) with respect to brake power for both fuels. In general, BTE increases with increase in BP, due to low power input requirement for higher power output at a given load as heat lost is reduced at higher loads. It was noticed that, BTE of B30 is far better than pure diesel for all injection pressures due to rich oxygen content in biodiesel. It was also identified at full load condition, diesel has registered higher brake thermal efficiency at 180 bar and 220 bar than standard injection pressure of 200 bar, whereas B30 has showed greater
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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.

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.2 Variation of BSFC with BP

Fig.3 Variation of BTE with BP

B. Characteristics of Emission

Fig.4 communicates the relationship between exhaust gas temperature (EGT) and brake power for both pure diesel and B30 at all injection pressures. Exhaust gas temperature and brake power are inversely proportional to each other since large amount of heat is wasted through exhaust. The result showed that, at all injection pressures the EGT of B30 is less than that of diesel for all the loads. It was observed at full load condition that, at 200 bar the difference is very large and is reduced by 12.79% compared to conventional diesel fuel.

Fig.5 illustrates the variation of Carbon dioxide (CO₂) emission with brake power for tested fuels. As the brake power increases the percentage of CO₂ getting increased. Faster movement of the fuel particles at higher injection pressures resulting in rapid vapourization causing increase in

Fig.6 depicts the disparity of Carbon monoxide (CO) emission with brake power for pure diesel and B30 at different injection pressures. In fact, the emissions of CO increase with increasing load. As the load increases, rich fuel-air mixture is burned thus forming more CO due to shortage of oxygen. The results revealed that from zero load to 75% load the percentage of CO for B30 is more than that of diesel fuel at all injection pressures, but at full load condition, at 180 bar the CO percentage is reduced by 4.5%, at 200 bar it is dramatically reduced by 71.97% and at 220 bar no reduction was found compared to fossil diesel.

Fig.7 shows the deviation of unburned hydrocarbon (UHC) emission along with increase in brake power. As per the results obtained during the experiment, the hydro carbon
percentages are gradually increased from zero to full 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. At full load condition and at 200 bar it was reduced by 15.56% when compared to pure diesel. pressures. 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. 6 Variation of CO Emission with BP

Fig. 8 Variation of NO\textsubscript{X} Emission with BP

Fig. 7 Variation of UHC Emission with BP

Fig. 9 Variation of Smoke Opacity with BP

C. Characteristics of Combustion

Fig. 10 represents the change of Cylinder peak pressure with brake power for both fuels at various injection pressures. From the graph it has been witnessed that, the cylinder peak pressure increases steadily with increase in brake power. In general, the peak pressure determines the quantity of fuel burned in premixed combustion phase in turn controlled by the ignition delay period. From zero load to full load the cylinder peak pressure was gradually increased, for all injection pressures. At full load condition the result reported that, at 180 bar and 220 bar the peak pressure was merely reduced by 0.47% and 0.22% respectively, but at 200 bar the peak pressure of B30 is more than that of diesel fuel by 2.66%.
Fig. 11 depicts the relation between maximum heat release rate (Max.HRR) and brake power. For all the injection pressures, the maximum heat release rate of biodiesel is less than that of fossil diesel. This is due to poor spray atomization as biodiesel possess high viscosity. At full load condition, max. heat release rate of B30 was reduced by 22.11% at 180 bar, 11.70% at 200 bar and 21.33% at 220 bar when compared to pure diesel.

Maximum peak pressure attained inside the cylinder depends upon the ignition delay. From the experimental data it was observed that, ignition delay was steadily reduced with one-degree variation from zero load to full load for all the injection pressures.

Fig. 12 Variation of Ignition Delay with BP

IV. CONCLUSIONS

A Single Cylinder four stroke diesel engine powered by pure diesel and B30 was tested successfully and the corresponding results were analyzed and discussed, hence the following conclusions are narrated based on the above evaluation at full load condition,

1. The BSFC of pure diesel and B30 are gone almost similar with small deviation of 0.01 Kg/Kw-hr for all injection pressures. At 200 bar B30 has registered minimum bsfc compared to fossil diesel.

2. The BTE of B30 was increased up to the injection pressure of 200 bar, then it was lowered a little at 220 bar. At 200 bar BTE was increased by 14.08% when compared to pure diesel.

3. A fluctuation was found in the measurement of EGT for modified injection pressures of 180 bar, 200 bar and 220 bar with 2°C of temperature difference, no trend was found.

4. The percentage of CO₂ emission was lowered with higher injection pressures for B30, when compared to conventional diesel.

5. The CO concentration of B30 was followed downward trend with higher injection pressures. It was found that, at the injection pressure of 220 bar CO concentration was reduced by 78.24% compared to Pure diesel at 200 bar.
6. The UHC emission was increased at the higher injection pressure of 220 bar, it is 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 NOx 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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AUTHORS PROFILE

Nambaya Charyulu Tatikonda received his B.E Degree in Mechanical Engineering from Karnataka University, Dharwad in 1994, and M.Tech in Thermal Engineering from JNTU Hyderabad in 2008. Now he is pursuing Ph. D from Bharath Institute of higher education and research, Chennai. At present he is working as Assistant Professor in the Department of Mechanical Engineering in Sree Vahini Institute of Science and Technology, Tiruvuru, Andhra Pradesh, India.

Dr. P. Naveenchandran received his B.E Degree in Mechanical Engineering from Annamalai University, Chidambaram in 1990, and M. Tech in Thermal Power from Annamalai University, Chidambaram in 1998. He was awarded with Ph. D from Universiti Technology, Petronas, Malaysia in the year 2011. He attended 20 conferences/workshops and published 20 papers in National and International journals. At present he is working as Professor in the Department of Automobile Engineering in Bharath Institute of Higher Education and Research, Chennai, Tamilnada, India.