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# EXPERIMENTAL INVESTIGATION ON PERFORMANCE PARAMETERS OF DIESEL ENGINE USING MICROALGAE BIODIESEL

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**ABSTRACT**

This study explores the utilization of algal oil methyl ester (AOME) derived from Spirulina spp. as a sustainable alternative to conventional diesel fuel. Algal oil was extracted using solvent extraction and the expeller method, followed by a transesterification process at 75°C for 48 hours using sodium hydroxide and methanol, achieving a conversion rate of 95% with excess methanol. The AOME was then blended with commercial diesel in varying ratios of 5%, 10%, 15%, and 20%. Performance and emission tests were conducted on a single-cylinder, four-stroke, naturally aspirated, water-cooled, direct injection diesel engine to assess the effects of these blends. The results revealed that the brake thermal efficiency (BTE) improved with increasing AOME content, with the 20% AOME blend (AOME20) demonstrating a BTE increase of 2.5% to 3.5% compared to pure diesel. The brake specific energy consumption (BSEC) decreased with AOME20, indicating higher fuel efficiency. Additionally, engine emissions, including hydrocarbons (HC) and nitrogen oxides (NOx), were reduced with the introduction of AOME, particularly under part-load and full-load conditions. The study concludes that AOME, particularly in the 20% blend ratio, is a viable and efficient biofuel alternative, offering enhanced engine performance and reduced emissions.

**Keywords:** Algal oil methyl ester (AOME), Transesterification, Diesel engine, Efficiency, Emissions, Sustainable energy, Spirulina spp.

## 1. INTRODUCTION

With a rapid increase in the demand of fossil fuel, decrease in the availability of crude oil supplies and greater environmental stringent norms on pollution has created enormous interest in researchers in formulating and testing biofuels in recent times. The most promising method for deriving biodiesel from renewable energy source is transesterification process. Many vegetables plants were found successful in the production of biodiesel like Neem, Jatropha, Karanja, Cotton seed, Rapeseed, Soyabean, etc. It has also been reported in the literature that the use of biodiesel considerably reduced emission and increased the performance of engine (Agarwal *et al.* 2001, 2007). Many researchers have reported on the possibility for production of biodiesel from algae. Algal growth is photosynthetic in nature (i.e) they mainly use sunlight along with nutrients for their growth. Chlorophyll A and Chlorophyll B are the main components which undergo metabolic activities. Algae have a capability of fixing atmospheric carbon di-oxide and can be grown in intensive culture on a non-arable land. Demirbas (2011) has reporter that algae can be converted into biodiesel, Bioethanol, bio hydrogen, bio oil and bio methane through bio-chemical and thermo chemical methods. Chen *et al.* (2011) have reported on the growth and oil content in blue green algae. He has analyzed the growth factor of algae with a significant change in quantity of nutrients and noticed that under nitrogen deficit condition, the oil content (lipid) was increased in algae with respect to time. In certain parts of India, Jatropha curcas plant commonly grown in hot climatic areas is one of the most promising source of biodiesel. Jatropha can be grown in waste lands and it can yield more than four times as much biodiesel per hectare as soyabean and ten times more than corn. But commercial cultivation of Jatropha raises several significant challenges in transesterification and cursin removal. Because of difficulties in procuring oil seeds and lack of infrastructure may obstruct the production of biodiesel. So far National Bioenergy Limited (NBL) and Southern biotechnologies India have embarked on biodiesel production from Jatropha curcas which has been set by National biodiesel mission developed by Government of India. Based on the above said limitations of Jatropha, an alternative feed stock for the generation of biodiesel is necessary. In the case microalgae is considered as the feed stock. Microalgae are a diverse group of prokaryotic and eukaryotic photosynthetic microorganism which grows rapidly due to their simple structure. Microalgae have been investigated for the production of biodiesel, bio-oil, bio-Syngas and bio-hydrogen. It was estimated to be more than 2,00,000 species of microalgae which are capable of producing lipids. On-going advances in cultivation techniques coupled with genetic manipulation of crucial metabolic networks will further enhance microalgae as an attractive platform for the production of numerous high value compounds. Microalgae with lipid content upto 60% grown in saline or sea water have the potential to be the source of biodiesel. Demirbas (2011) studied the production of biodiesel from two algae samples (Cladophora fracta and Chlorella protothecoid). He stated that microalgae can be converted into biodiesel, bio-ethanol, bio oil, bio hydrogen and bio methane via thermo chemical and bio chemical methods. In this study, the yield of hydrogen fuel by pyrolysis and steam gasification with temperature variation were investigated. It resulted in 54.7% and 57.6% increase by volume for C.fracta and C.protothecoid. Present paper studied the performance characteristics of algae based biodiesel and its impacts on performance of engine and its environmental effects.

## 2. SAMPLE PREPARATION

### 2.1. Growth media selection

A growth medium is a liquid which contains various nutrients required for the algal growth. The specialized media is prepared in the form of broth and the algal stain is allowed to grow in it for a specified period of time in the presence of illumination and aeration. The growth of spirulina spp. cannot be clearly defined because individual elements present in the media composition affects the growth at various stages.

Figure 1 Diagram showing transesterified algal oil methyl ester

**2.2. Details of blending**

The AOME-Diesel are blended at 5%, 10%, 15% and 20% ratios to balance the content of oxygen present in AOME (5% to 9% of $O_2$) which leads to better combustion efficiency and lower emission formation. The ester of AOME was identified as Hexadecanoic acid-methyl ester (Palmitic acid), 6,9,12,15 Docosatetraenoic acid Methyl ester (Linoleic acid), 16 Octadecenoic acid methyl ester (Oleic acid), Heptadecanoic acid 16 methyl methyl (Stearic acid) ester using spectral studies and confirmed using Infrared analysis.

**2.3. Experimental setup**

Figure 2 shows the photographic views of experimental setup and sensors used for measurements. The specification of the engine is tabulated in Table 2.

Table 2 Specification of engine

| **Name** | **Description** |
|---|---|
| Make and Model | Kirloskar DM 10 |
| Bore and Stroke | 102 mm X 116 mm |
| Compression Ratio | 17.5 : 1 |
| Rated Speed | 1500 rpm |
| Cubic Capacity | 0.948 liters |
| Power | 7.4 kW at 1500 rpm |
| Injection timing | $26^o$ bTDC |
| Injector opening pressure | 210 bar |
| Valve timing | |
| Inlet valve opening (bTDC) | $4.5^0$ |
| Inlet valve closing (aTDC) | $35.5^0$ |
| Exhaust valve opening (bTDC) | $35.5^0$ |
| Exhaust valve closing (aTDC) | $4.5^0$ |

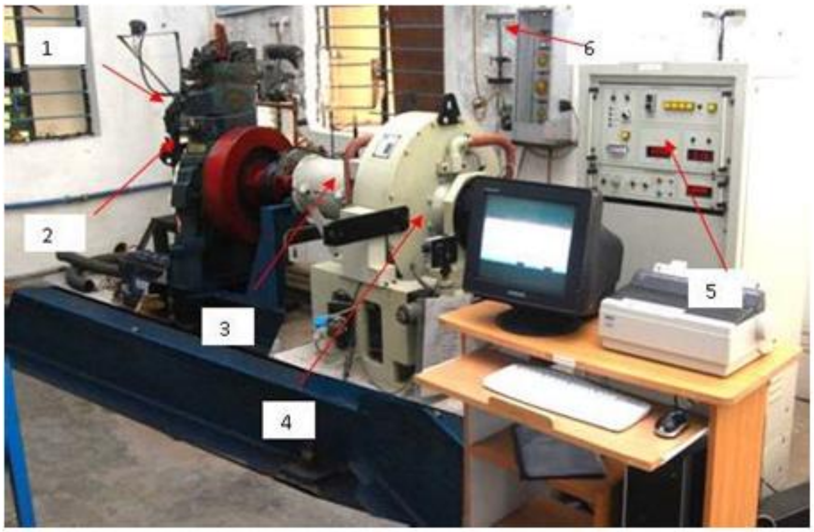


Figure 2 Engine setup (a) Kirloskar engine (b) Flywheel (c) Dynamometer (d) Data acquisition (e) Control unit (f) Flow meter

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of combustion and engine performance parameters

#### 3.1.1. Comparison of Brake specific energy consumption and Brake Thermal Efficiency

At a specified Brake mean effective pressure, the specific fuel consumption shows an increasing trend because of the decrease in the calorific value of the fuel with increasing blending ratio (i.e.) from straight diesel to AOME 20% blend. It gives us information that for the same power output, the engine will consume more quantity of AOME blended fuel at increasing blend ratio. At higher blend ratio, the liberation of oxygen to the combustion process is also higher which leads to high combustion pressure and power output. During this period, the combustion is very rapid and more complex (James *et al.*2007). Better combustion was achieved in low temperature ranges which also improve the thermal efficiency, specific energy consumption and power.

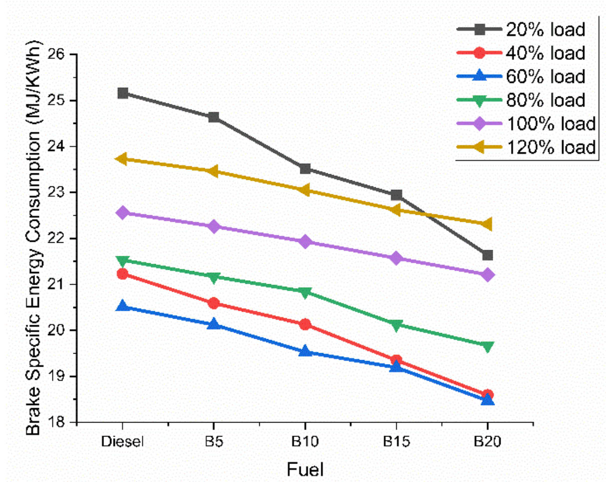


Figure 3 Comparison of Brake specific energy consumption for diesel, B5, B10, B15 and B20 at all load condition

Figure 3 shows the comparison of brake specific energy consumption with brake mean effective pressure derived from the base of in- cylinder pressure data of the engine operating between low load and 20% above the rated load for straight diesel, AOME 5%, 10%, 15% and 20% blend ratios. Is can be noticed that brake specific energy consumption of straight diesel at low load was 25.16 MJ/kW-hr while AOME blends shows constant decrease in BSEC at the similar load by 3% to 5%. This may be due to reduction in the calorific value of the fuel as the AOME blends were increased. A similar trend was seen throughout all the load condition as shown in figure 3.

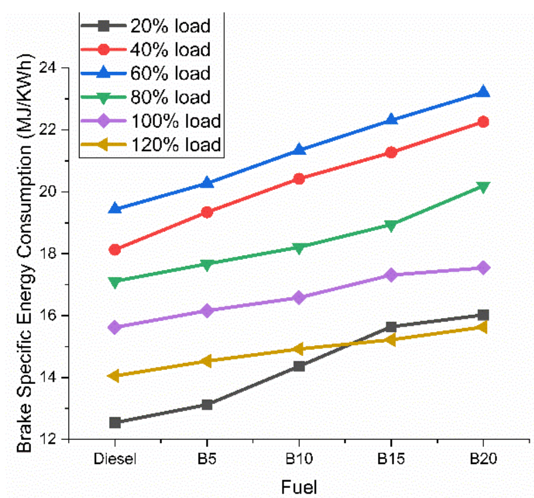


Figure 4 Comparison of Brake thermal energy for diesel, B5, B10, B15 and B20 at all load condition

The brake thermal efficiency which was estimated considering the energy output to heat input shows a moderate increase from 4% to 8% at increasing AOME blends as shown in Figure 4. This may be due to liberation of $O_2$ molecules at the right time during combustion (Subramanian *et al.* 2009). This also leads to combustion taking place at low temperature range and as a result, the power output also shows a moderate change.

Figure 4 shows the comparison of brake thermal efficiency for straight diesel, AOME 5%, 10%, 15% and 20% blend ratio at low load, part load, full load and 20% above the rated load. The brake thermal efficiency of straight diesel at 20% load was found to be 12.54% and increased up to 19.43% at part load and decreased to 14.05% at 20% above the rated load. The AOME blends show an increasing trend of brake thermal efficiency 23.21% at part load condition for AOME 20% blend.

It was observed initially with increasing brake mean effective pressure, brake thermal efficiency of AOME blends also increases together with diesel. The brake thermal efficiencies of AOME blends were found to be higher than diesel fuel throughout the entire range of operation which may be due to decrease in brake specific energy consumption for AOME blends as compared with straight diesel.

At higher blend ratio, the fuel consumption was found to be increased due to decrease in calorific value. Since the combustion is taking place in low temperature range, the peak flame temperature was also found to be lower with increasing AOME blends, but overall studies reveals that at higher AOME blend ratio (i.e) more amount of $O_2$ presence leads to higher combustion efficiency at higher brake mean effective pressure. The AOME 20% blend shows better combustion characteristics when compared to other blend ratio due to the presence of more oxygen molecules inside the micro-air fuel parcels. When the AOME is blended with straight diesel higher than 20% ratio, the combustion behavior was slightly altered and deteriorated in performance may be due to the following reasons:

The calorific value of the blended fuel decreases drastically as the blending ratio in increased beyond 20%. At temperature above 1900 K, Hexadecanoic acid methyl ester which is present in prominent quantity undergoes a chemical reaction to form behenic acid and Arachidic acid and further reduces the calorific value of the fuel by 8%. This can be overcome by adding 2% of di-ethyl ether to the AOME blends above 20% ratio and incorporating a preheater at the fuel inlet (Yousef *et al.* 2011). The density of the fuel is gradually decreased with increase in AOME blends with straight diesel. The in-cylinder pressure and rate of heat release show minimal variations as the blend ratio was increased up to 20% and the peak in-cylinder pressure was decreased by 10% at full load and 6.6% at part load operation as shown in Figure 4.

### 3..2. Heat release rate

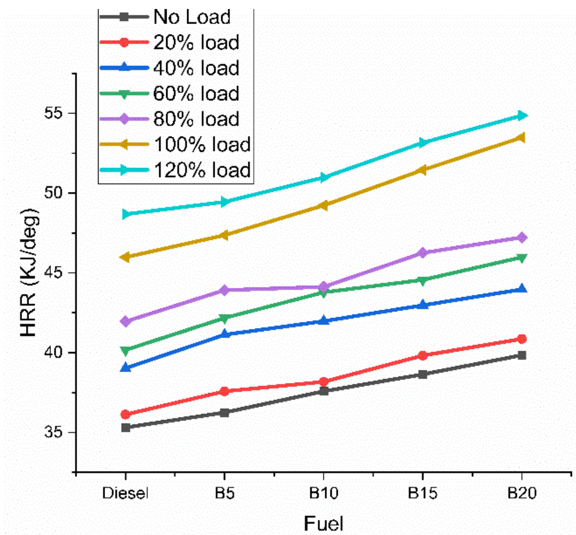


Figure 5 Comparison of HRR for diesel, B5, B10, B15 and B20 at all load condition

AOME 20% blend shows maximum heat release upto 47 kJ/deg at full load and 44 kJ/deg at part load condition which is 3% to 4% higher than straight diesel. Generally, it is observed that all the AOME blends tend to increase maximum peak pressure, rate of pressure rise and heat release rate especially at high loading condition conditions. This is because of the availability of free oxygen liberated from AOME blends which helps in complete combustion and premixed combustion. AOME blends show minimal improvement in low and part loading conditions.

### 3.3. Impacts of blended biodiesel on environment

#### 3.3.1. Hydrocarbon emissions

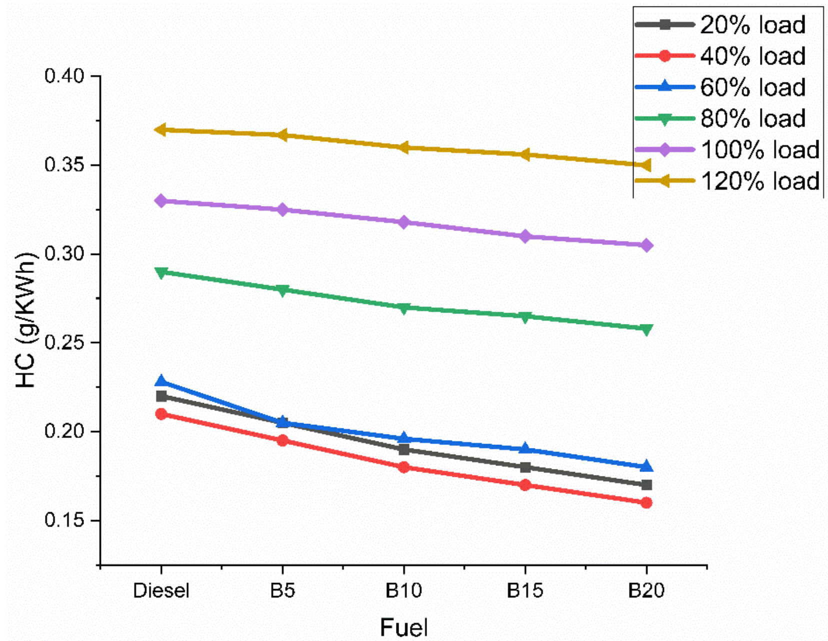


Figure 6 Comparison of HC emissions for diesel, B5, B10, B15 and B20 at all load condition

The AOME blends of 5%, 10%, 15% and 20% shows moderate effect in the reduction of HC emission. This may be due to presence and liberation of oxygen molecules at higher blending ratios. The oxygen molecules actively participate in the combustion and transit heat energy to all the micro air fuel particles in the combustion chamber and thereby initiating complete combustion. Five Gas Analyzer is used to measure hydrocarbon level in ppm. The value is converted into mass emission standards (gm / kW-hr). The Figure 6 shows various trends of HC emission for Straight diesel, AOME 5%, AOME 10%, AOME 15% and AOME 20% blend ratios at various loading conditions. At low blend ratio, the curve shows higher HC emission and at higher blend ratios, the HC emission is reduced. This was because, at higher blend ratio of AOME, the Cetane number of the fuel is increased which causes lesser ignition delay. Also, more quantity of oxygen is present in the higher AOME blends, which takes part in the combustion ensuring complete combustion. At higher blend ratio (i.e at AOME 20% blend), solubility and oxygen balance are perfectly matched so that proper vaporization takes place inside the combustion chamber which also leads to better combustion (Nurun *et al.* 2009).

At blend ratio more than AOME 20%, oxygen imbalance takes place which ultimately leads to poor solubility with the micro air fuel particles and results in negative improvement of hydrocarbon emission. Due to the presence of excess oxygen during the late combustion phase were heat release rate continues till the end of expansion stroke also leads to more hydrocarbon emission.

### 3.3.2. Influence of Oxides of Nitrogen ($NO_X$)

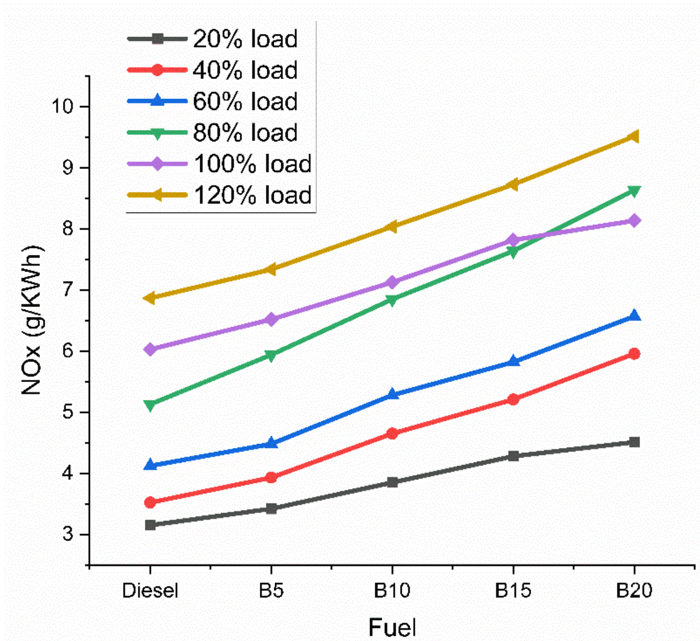


Figure 7 Comparison of NOx emissions for diesel, B5, B10, B15 and B20 at all load condition

Five gas analyzer is used for measuring $NO_x$ in ppm and converted into mass emission standards using standards. The Figure 7 reveals the variation of $NO_x$ at various loading condition for Straight diesel, AOME 5%, AOME 10%, AOME 15% and AOME 20% blend ratio. The emission trends show that there is a gradual increase in $NO_x$ with the increase in blend ratio especially at higher loading conditions. There is a 4% increase of $NO_x$ emission as the AOME blend ratio increases from 10% to 15%.

## 4. CONCLUSION

Algal oil was extracted from Arthrospira maxima (Spirulina *Spp.*) through solvent extraction & expeller method. Algal oil methyl ester was formed by transesterification of algal oil with sodium hydroxide and methanol. The AOME was mixed with commercial diesel in blend ratios of 5%, 10%, 15% and 20%. The experiments were conducted in a single cylinder four stroke naturally aspirated water-cooled direct injection diesel engine to evaluate the effect of diesel and AOME blends. Based on the result, the following conclusions were drawn:

- The transesterification process was accomplished at 75°C for 48 hrs with sodium hydroxide and methanol. The transesterification rate was found to be 95% when excess methanol is added.
- The brake thermal efficiency was found to increase with addition of algal oil methyl ester.
- High performance blend ratio is AOME 20% and optimum performance was seen in AOME 15%. Based on the result of brake thermal efficiency, AOME 20% showed an increase of 2.5% to 3.5% than diesel. The brake specific energy consumption showed a decreasing trend with diesel as higher BSEC and AOME 20% blend as lower BSEC.
- The entire AOME blending ratio was found to have effect in engine emissions on part load and full load. HC and $NO_x$ were found to decrease with addition of AOME.

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