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Comparative analysis for performance characteristics of a compression ignition engine running on microalgae methyl ester and diesel blends with base engine and coated engine

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ABSTRACT
In a standard internal combustion engine, a large amount of heat energy is being wasted through the cooling and exhaust systems. So, to minimize these losses one advanced technology for coating applications grows rapidly. Hence, to improve engine performance and fuel economy one or more parts of the combustion chamber such as piston crown, inlet valves, exhaust valves and cylinder head are getting coated with ceramic materials without changing the original dimensions. The present work deals with the performance characteristics of a single-cylinder diesel engine with an eddy current dynamometer loading fuelled with microalgae methyl ester (MME) when the piston crown was coated with yttria stabilized zirconia of thickness 350 microns equal to 0.35mm of thickness using plasma spray coating technique. Test samples were prepared and designated as MME10D90(B10), MME20D80(B20), and MME30D70(B30). Tests were conducted and comparison is done with the performance results of coated and uncoated piston named as the base engine and coated engine respectively. Finally, the experimental results revealed that, at full load condition, the BSFC, BTE, TFC of the blend MME30D70(B30) with the coated engine were improved by 3.77%, 4.29%, and 7.81% respectively compared to the base engine.
***Keywords* -** Microalgae Methyl Ester, Zirconium Oxide, Ceramic Coating, Plasma Spray Coating Technique, Engine Performance Characteristics, Brake Thermal Efficiency, Brake Specific Fuel Consumption.

I. INTRODUCTION

Renewable energy is a hopeful source of energy for future success to keep the environment in a safe zone. Bioenergy was anticipated to diminish the dependency on conventional fossil fuels with its connected governmental and lucrative infirmity, minimize the greenhouse emissions and other related issues to reinvigorate the financial wealth to increase the demand and prices of the agricultural outcomes. It had been expected that shortly half the universal energy demand is going to be fulfilled by renewable energy by 2040. At present, Biomass is the most favourable renewable resource of energy and it might be continued in the upcoming days. It had been judged that the current available petroleum reserves will vanish within a brief period of nearly 50 years at the present rate of utilization [1]. In India, the vehicle populace formation has displayed an important difference during the time period 1951-2015. But inappropriately, the development in vehicles and availability of petroleum reserves had become inversely proportional to each other, and also there are bigger ecological uncompromising rules on pollution, had produced a widespread interest in scholars to precise and test the bio-fuels fit lately. As of now, several vegetable seeds including non-edible and edible such as Jatropha, Neem, Karanja, Cottonseed, Pongamia, Rapeseed, and Soybean, etc. were found positive in the biodiesel production. The biodiesels obtained till now are not sufficient to encounter the worldwide requirement of fuel therefore exploring other possible sources as an auxiliary for conservative fuels is a requirement [2]. During this journey to seek out an appropriate feedstock which may be edible or non-edible for producing biodiesel, several investigations on various biodiesels in a diesel engine with and without engine modification are discussed as under, Agarwal A.K. et. al (2001) reported that a 20% blend of biodiesel gave the best performance amongst all blends. It gave a net advantage of 2.5% in peak thermal efficiency and there was a substantial reduction in smoke opacity values, and also, they have stated that, biodiesel can be used as an alternative, environment-friendly fuel in existing diesel engines without substantial hardware modification [3]. Deepak Agarwal and Avinash Kumar Agarwal (2007) claims that, while the single-cylinder four-stroke diesel engine operating by jatropha oil preheated blends the performance and emission parameters were found very close pure diesel for lower blend concentrations and for higher blend concentrations they observed to be marginally inferior [4]. Avinash Kumar Agarwal et. al (2009) has studied the performance and emission characteristics of a single-cylinder diesel engine when it was fueled with Karanja biodiesel, and it was reported that they have obtained better spray and atomization characteristics when biodiesel was preheated [5]. L.Tarabet et. al (2014) conducted an experimental investigation on a modified DI diesel engine operated with Eucalyptus biodiesel and natural gas under dual fuel mode and results in lower NOx emissions than the conventional diesel fuel mode [6]. Ayhan Demirbas et. al (2011) stated that, algae have the potentiality to fix the atmospheric CO2 and can be grown in intensive culture on a non-arable land [7]. Chisti Y (2007) claims that the demand for fuel in the transportation industry can only be covered by microalgae as a renewable source and it had been reported that microalgae can produce an equivalent amount of biodiesel compared to rapeseed or soybean crops using around 49–132 times less land [8]. Attilio Converti et. al (2009) stated that, the lipid content of microalgae decreased from 14.7 % to 5.90 % when the growing temperature increased from 25 to 30^0C [9]. Nambaya Charyulu Tatikonda, and P. Naveenchandran (2019) investigated the behaviour a compression ignition engine under the influence of microalgae methyl ester and diesel blends, it has been reported that the blend B30 (30% microalgae methyl ester + 70% pure diesel) produced better performance and emission results compared to that of fossil diesel at standard operating parameters [10]. Nambaya Charyulu Tatikonda, and P. Naveenchandran (2019) have reported the impact of injection pressure on the performance and emission characteristics of a direct injection diesel engine driven with microalgae methyl ester at 30% and stated that, no significant improvement was found with modified injection pressures [11]. Vinay Kumar. D and Ravi Kumar P. (2017) have reviewed the effect of insulation with ceramic materials on the performance, combustion, and emission characteristics of a diesel engine and discussed the reasons for each deviation [12]. Huseyin Aydin (2013) reported his experimental results from zirconium Oxide coated engine with cotton seed, sunflower pure vegetable oils blended with diesel, and stated that engine power, torque and fuel consumption were improved, emissions were decreased with coated engine [13]. M.J. Abedin et. al (2014) have investigated the contradictory results of several researches on low heat rejection engines and said that, more investigation with improved engine modification and design are required to explore the potentiality of LHR engine [14]. Selman Aydin et. al (2015) experimentally reported the influence of thermal barrier coating on engine performance and emissions and claimed that by coating process, partial increases were observed in power and engine noise, while partial decrease were found in brake specific fuel consumption, besides partial reductions were seen in emissions except nitrogen oxides [15]. V. Karthickeyan et. al (2016) reported their experimental results on diesel engine coated with partially stabilized zirconia powered with various non-edible oils at 20:80 ratio with diesel. the report says, higher thermal efficiency, lower brake specific fuel consumption along with lower emissions were observed [16]. V. Karthickeyan (2017) has tested the diesel engine coated with partially stabilized zirconia running on orange oil methyl ester at 20% blend with diesel and observed that increase in brake thermal efficiency, reduction in brake specific fuel consumption and emissions [17]. M. Selvam et. al (2018) experimented on single cylinder diesel engine coated with yttria stabilized zirconia and found increment in brake thermal efficiency and reduction in brake specific fuel consumption, as well as in emissions, increment was observed in nitrogen oxide [18].

The above studies reveal that the diesel-biodiesel blends can be used as alternative fuels for diesel engines with and without engine modification such as thermal barrier coatings. Recent research has shown that the use of diesel biodiesel blends can substantially increase engine performance and reduce emissions by doping the fuel or coating inside the combustion chamber. They had also suggested some alternative fuels which are friendly to the atmosphere especially like microalgae biodiesel. Therefore, in the present study Microalgae methyl ester was chosen as a fuel, because in the previous research [10,11] microalgae methyl ester blended with pure diesel showed better performance characteristics than that of pure diesel, and yttria stabilized zirconia was chosen as thermal barrier coating for piston crown as this combination was not found so far in the past research, Hence, the present work has found the research gap in this area and it reveals the comparison between the base engine and coated engine for the performance characteristics when the compression ignition engine was run with the blends of microalgae methyl ester and mineral diesel in the blending ratios 10:90, 20:80 and 30:70 respectively.

II. MATERIALS AND METHODS

A. Preparation of Biodiesel

Microalgae crude oil was purchased from biodiesel producers of Chidambaram, in Tamilnadu state. The Microalgae crude oil is subjected to transesterification in our laboratory as follows,

Crude microalgae oil is measured 1000 ml and is taken in a round bottom flask,18 grams of potassium hydroxide as an alkaline catalyst (KOH) is weighed and 250 ml of methyl alcohol is taken in a beaker [10, 11]. First of all, KOH is mixed with the alcohol and it is stirred until they are properly dissolved with each other. Then the crude microalgae oil already taken in a round bottom flask is stirred with a magnetic stirrer and simultaneously heated with the help of a heating coil. The speed of the stirrer should be minimum (approximately 110 rpm) and when the temperature of the crude microalgae oil reaches 60^0c the KOH-Alcohol solution is poured into the crude microalgae oil container and the container is closed with airtight. Now the solution is stirred at high speeds (approximately 700-800 rpm). Care must be taken that the temperature does not exceed 60^0c as the methanol evaporates at a temperature higher than 60^0c, also the KOH-Alcohol solution mixes with the crude microalgae oil only at 60^0c. To prevent the methanol loss during a reaction, a water-cooled condenser was used to condensate the vapours and reflux it back to the reactor. After stirring the Oil-KOH-Alcohol solution at 60^0c for two hours, the solution is transferred to a separating funnel, and then it was allowed to cool overnight without stirring. After complete cooling two layers were found, the bottom layer consisted of glycerol and the top layer was the biodiesel i.e., Microalgae methyl ester. The biodiesel is washed with water, (preferably distilled water) repeatedly till ensuring that no soap content is present in the biodiesel. Now this biodiesel is heated at 100^0C for a while to vapourize the water content in it. Finally, the resulting product is the microalgae biodiesel which readies for use [10, 11]. The transesterification process was depicted in the Figure 1.

B. Preparation of Biodiesel-Diesel blends

Microalgae methyl ester and pure diesel blends were prepared for 500 ml quantity, firstly by mixing 50 ml of microalgae methyl ester into 450 ml of pure diesel with the aid of magnetic stirrer for 5-10 minutes, and it was labeled as MME10D90 briefly B10, and same procedure was followed to prepare another two blends and were labeled as MME20D80 briefly B20, and MME30D70 briefly B30. The test samples were shown in the Figure 2, and the Corresponding physicochemical properties of fuel samples MME, B10, B20, and B30 were shown in the Table 1.

C. Preparation of Coated Piston

In the present investigation, the piston crown was coated with yttria stabilized zirconia of 0.35 mm thickness to achieve semi low heat rejection (LHR) engine which withstands higher temperature in the combustion chamber that promotes the combustion. The coating of the piston crown was done at Spraymet Surface Technologies, Pvt. Ltd., Bangalore. The objective of the present study is to improve the performance of a diesel engine with ZrO_2 coated piston using Microalgae methyl ester blends with various ratios ranging from 10% to 30% at different load conditions. The measured values are analyzed and compared with the base engine running with the same blends and pure diesel. The piston before coating and after coating were shown in the Figure 3.

D. Experimental Setup

The present study was carried out to find the influence of microalgae methyl ester blends such as MME10D90(B10), MME20D80(B20), and

MME30D70(B30) on the performance of a direct injection compression ignition diesel engine. The engine selected for this investigation is Kirloskar made single- cylinder, four-stroke, direct injection, water cooled diesel engine of 5.2 KW brake power at constant speed of 1500 rpm [10,11]. The specifications of the engine are depicted in Table 2. This engine was associated with eddy current dynamometer with control systems. The engine is provided with crank angle sensor, thermocouples to measure the temperature of exhaust gas, and water. The photographic view of experimental setup is viewed in Figure 4.

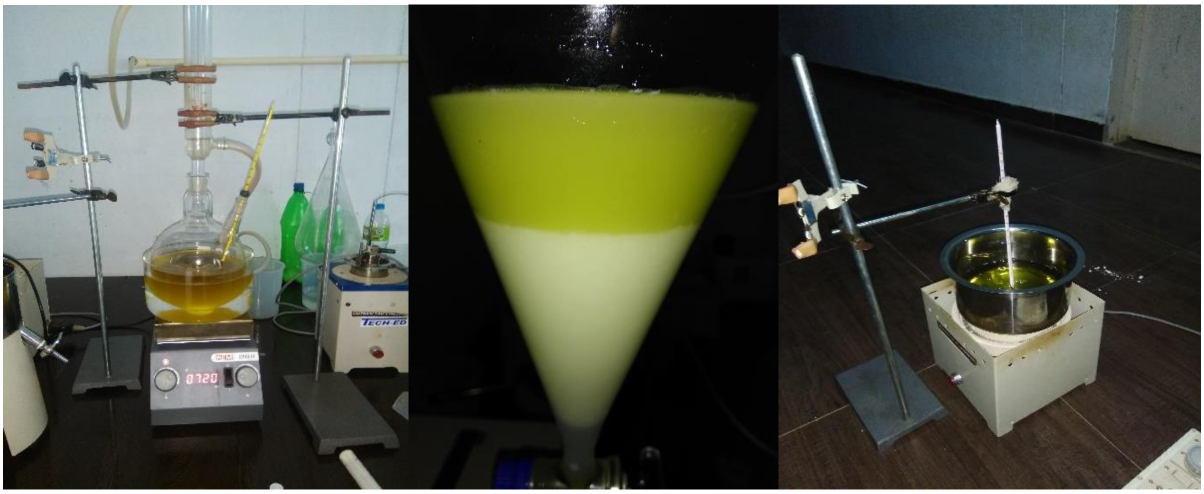

Figure 1. Transesterification Process

Figure 2. Test Samples

Table 1. Physicochemical Properties of Fuel Samples

Fuel Property	Diesel Specifications ASTMD975	Biodiesel Specifications ASTMD6751	MME	MME10D90 (B10)	MME20D80 (B20)	MME30D70 (B30)
Density (kg/m^3)	840	810 – 900	872.6	820.20	825.40	827.4
Kinematic Viscosity (mm^2 / Sec) @ 40^{0}c	3.8	1.9 – 6.0	5.13	2.75	2.93	3.11
Flash Point (^{0}c)	60	≥ 130	178	56	57	58
Cetane Index	47	38 min.	46.69	54.64	54.85	55.06
Calorific Value (KJ/Kg)	42,500	35,000 min	38,963	42,551	41,921	41,291

Figure 3. Piston before coating and after coating

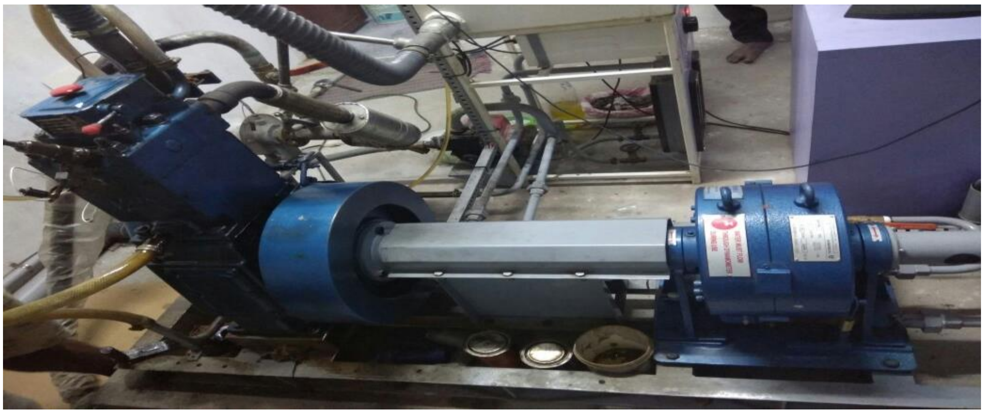

Figure 4. Photographic View of Experimental Setup [10, 11]

Table 2. Specifications of the Experimental Setup [10, 11]

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

E. Experimental Procedure

Firstly, allowed the engine to run with pure diesel at rated speed (1500 rpm) for a few minutes, and then vary the load from zero to full load in steps (0, 25%, 50%, 75%, and 100%) noted down the readings of performance parameters at each load. Secondly, powered the engine with B10, B20, and B30 and experiment was repeated, and all the performance related readings were taken, and thirdly, piston of base engine was replaced with ZrO_2 coated piston and run the engine again with the same test samples such as B10, B20, and

B30, recorded all the necessary readings as above, finally the experimental results were analyzed and comparison was made between base engine data and coated engine data along with pure diesel data.

F. Formulae

Brake power of the Engine is given by,

$$BP = \frac{2\Pi N(w \times 9.81 \times R_m)}{(60 \times 1000)} kW$$

Where, w = Load on the engine, in kg,
N = Speed of the engine, in rpm,
R_m= Radius of Dynamometer Arm Length, m

Mass of fuel consumption is given by,

$$m_f = \frac{(q \times Density\ of\ fuel)}{t} \frac{kg}{Sec}$$

Where, q = Volume of fuel consumed
$=(10 \times 10^6)m^3$,
t = Time taken for 10 cc of fuel consumption sec,

Brake Specific Fuel Consumption is given by,

$$BSFC = \left(\frac{m_f}{BP}\right) \times 3600 \frac{kg}{kW - hr}$$

Brake Thermal Efficiency is given by

$$BTE = \frac{B.P}{(m_f \times C.V)} \%$$

Where, C.V = Calorific Value of the Fuel, kJ/kg

Total Fuel Consumption is given by

$$TFC = m_f \times 3600 \frac{kg}{hr}$$

III. RESULTS AND DISCUSSION

Performance Characteristics

Figure 5. represents the relation between the brake power (BP) and brake specific fuel consumption (BSFC) of all the test samples. It is evident from the graph that, for all the test fuels the BSFC decreased with increased brake power. Generally, brake specific fuel consumption is the measure of how the supplied fuel energy to the engine is converted into brake power and it can be defined as the amount of fuel consumed in unit time for generating kw power. The experimental result revealed that, the bsfc of test fuels operated with coated engine was improved compared to pure diesel and base engine. Decrease in BSFC is due to the reduction in the fuel consumption and improved energy conversion rate at all loading conditions in the coated engine. This may be due to the increased temperature of the combustion chamber walls, which increase the temperature of the fuel issued from the heated fuel injecting nozzle resulting in the reduced fuel viscosity and better combustion of the fuel. At maximum load condition, MME30D70 (B30) with coated engine has registered lowest BSFC amongst all and it was improved by 9.80% compared to pure diesel and by 3.77% compared to base engine data.

Figure 6. shows the variation of brake thermal efficiency (BTE) with brake power (BP) for all the test fuels. It can be noticed from the experimental results that, the BTE of all the test samples under coated engine was higher than that of base engine at all load conditions. This is due to the fact that, the thermal resistance of the piston crown which cannot allow the heat energy to coolant there by reducing the fuel consumption for the same amount of power output. It can be observed that, at maximum load condition, the BTE of MME30D70 (B30) with coated engine is higher than that of pure diesel and base engine data. At full load condition, diesel has recorded 33.40 % of BTE, MME30D70 (B30) with base engine has recorded 36.36% of BTE and with coated engine has recorded 37.92% BTE, therefore for coated engine the BTE of MME30D70 (B30) was increased by 13.54% compared to pure diesel and by 4.29% compared to base engine data.

Figure 7. depicts the variation of total fuel consumption (TFC) in kg/hr with brake power for all test samples. TFC is used to measure the quantity of fuel consumed by the engine per unit time while the engine producing a certain amount of power. It was revealed from the results that, the TFC increases with increase in brake power but the values recorded for coated engine shown lower than that base engine and pure diesel. this may due to the rise in temperature inside the combustion chamber with thermally partial insulation, then engine requires less amount of fuel to produce same amount of power when it was not insulated. Finally, it was shown at full load condition that, the TFC of MME30D70 (B30) with coated engine was improved by 7.81% compared to MME30D70 (B30) with base engine and by 9.92% compared with that of pure diesel.

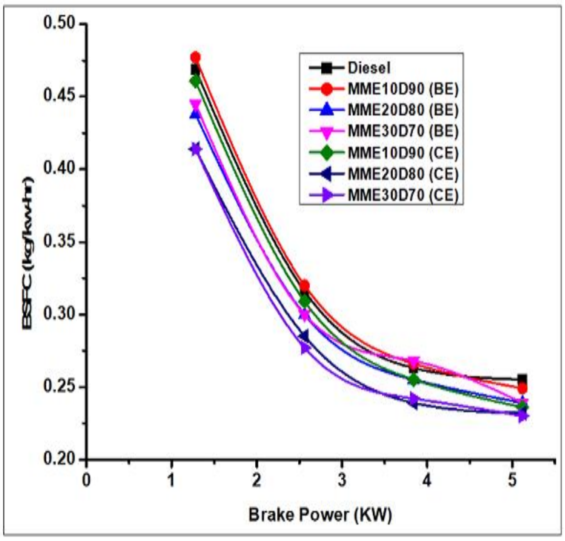

Figure 5. BP Vs BSFC

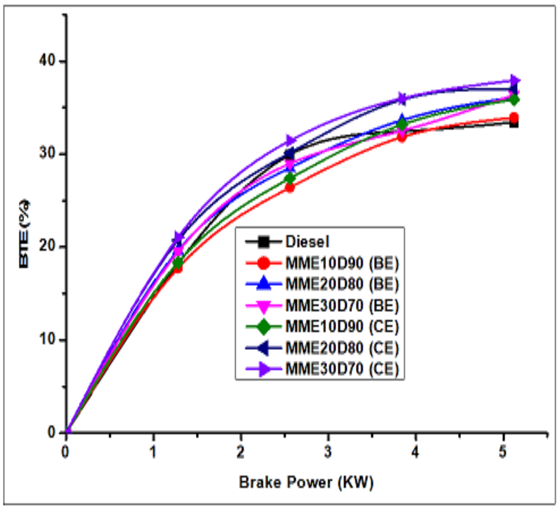

Figure 6. BP Vs BTE

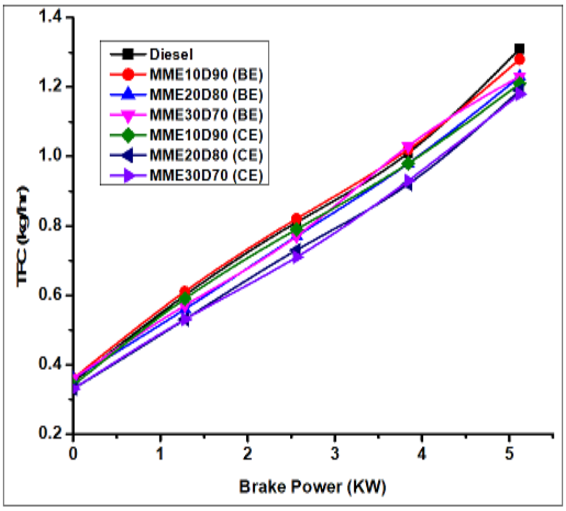

Figure 7. BP Vs BTE

IV. CONCLUSIONS

The performance characteristics of compression ignition engine powered with conventional diesel, diesel and biodiesel blends were investigated with base engine and coated engine. The conclusions of this investigation at full load condition are as under,

- In general, the brake specific fuel consumption decreases with increase in load on the engine, among all the blends, MME30D70 (B30) with coated engine has registered lowest BSFC amongst all and it was improved by 9.80% compared to pure diesel and by 3.77% compared to base engine data.
- Diesel has recorded 33.40 % of BTE, MME30D70 (B30) with base engine has recorded 36.36% of BTE and with coated engine has recorded 37.92% BTE, therefore for coated engine the BTE of MME30D70 (B0) was increased by 13.54% compared to pure diesel and by 4.29% compared to base engine data.
- The TFC of MME30D70 (B30) with coated engine was improved by 7.81% compared to MME30D70 (B30) with base engine and by 9.92% compared to pure diesel.

From the above conclusions it can be noticed that, as far as the performance parameters such as BSFC, BTE and TFC are concerned, out of all the blends MME30D70 (B30) with coated piston has showed better results and it was reported as the optimum blend with coated engine. In the future, this experimentation can be extended to find out the emission and combustion characteristics of the same engine with and without piston coating when it is fuelled with the same blends

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