Comparative Analysis of Performance Characteristics of A Compression Ignition Engine Fuelled with Cymbopogon Oil Methyl Ester and Diesel Blends with Base Engine and Coated Engine

Nambaya Charyulu Tatikonda[1]
[1]Faculty, Department of Mechanical Engineering,
Sree Vahini Institute of Science and Technology,
Tiruvuru, Andhra Pradesh, India

E. Rajesh[2], D. Konda[2], G. Ganesh[2],
G. Sarparaju[2], J. Bhanu Prakash[2]
[2]UG Students, Department of Mechanical Engineering,
Sree Vahini Institute of Science and Technology,
Tiruvuru, Andhra Pradesh, India

***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 Cymbopogon (Lemongrass) oil methyl ester (CME) 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 CME10D90(B10), CME20D80(B20), and CME30D70(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, and TFC of the blend CME10D90(B10) with the coated engine were improved by 3.61%, 4.05%, and 3.91% respectively compared to that of the base engine.**

Keywords–Cymbopogon Methyl Ester, Yttria Stabilized Zirconia, Ceramic Coating, Plasma Spray Coating Technique, Engine Performance Characteristics, Brake Thermal Efficiency, Brake Specific Fuel Consumption, Total Fuel consumption

I. INTRODUCTION

Diesel engines are playing a very dominating role in the fields of transportation and power generation. from the past few years we are witnessing an energy crisis especially in the sector of the automobile industry due to the unavailability of petroleum products according to the demand, and also escalating oil prices. Not only due to the demand and supply of petroleum, moreover the environmental concerns, there is much need for an alternative to mineral diesel. All such reasons made the researchers to focus their research to find a suitable solution to fix this issue. Most of the researchers have suggested several types of biofuels extracted from various sources of feedstocks such as edible seeds, non-edible edible seeds, and biomass etc., and now biodiesel from algae is getting more focus among all.

Though the biodiesel has the potential to replace the conventional diesel fuel, it makes a significant impact on diesel engine combustion due to lower combustion temperature, lower calorific value, higher viscosity and the transesterification reactant also influences the engine performance and emissions. Hence in order to make biodiesel more attractive towards performance and emission features, the researchers concentrated to improve the biodiesel efficiency. Different performance enhancement techniques such as changing injection pressures and timings, different compression ratios, adding nano fuel additives, coating the piston crown and valves, exhaust gas recirculation, water emulsion, and selective catalytic converters, etc., are being used [1]. The present literature review reports the various research conducted on compression ignition engines using different kinds of biodiesel and pure diesel blends and their related issues under various techniques.

Ganapathy et al (2011) investigated the performance, emission and combustion parameters of a compression ignition engine using Jatropha biodiesel at various injection timings, and found that on advanced injection timing, the performance, combustion and emission was better than the rated timing [2]. Nambaya Charyulu Tatikonda, P. Naveenchandran (2019) investigated the behaviour a compression ignition engine under the influence of microalgae methyl ester at various proportions with pure diesel at the range of 10 to 30% and found 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 [3]. Avinash Kumar Agarwal et al (2010) has studied the performance and emission characteristics of 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 [4]. Deepak Agarwal and Avinash Kumar Agarwal (2007) claims that, while the single cylinder four stroke diesel engine operating

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 05, May-2020

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 [5]. 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 [6]. Agarwal A.K. et al (2001) reported that, 20% blend of biodiesel gave the best performance amongst all blends. It gave net advantage of 2.5% in peak thermal efficiency and there was 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 [7]. G. Vinoth and P. Balaguru (2019) have studied the performance characteristics of lemongrass oil in a single cylinder diesel engine at various injection pressures and found that, the blend B20 has produced optimum values of specific fuel consumption, brake thermal efficiency, and emission parameters at modified injection pressure of 240 bar [8]. T. Nambaya Charyulu et. al (2020) have studied the impact of Artocurpus Heterophyllus methyl ester on the behavior of a compression ignition engine and stated that, 30% of blend explored better results towards performance and emission than that of pure diesel [9]. Ashok Kumar Jalasutram et. al (2019) stated as per the outcomes of the experiment conducted on a single cylinder direct injection diesel engine with lemongrass biodiesel and pure diesel blends, that the brake thermal efficiency has found to be higher for B50, and specific fuel consumption is increased for the lemongrass biodiesel blends [10]. Venugopal V et. al (2014) have reported that, Lemongrass biodiesel and pure diesel blends at 30:70 ratio has registered improved values of brake specific fuel consumption and brake thermal efficiency as far as performance characteristics are concerned [11]. Nambaya Charyulu Tatikonda and P. Naveenchandran (2019) reported the experimental results related to the investigation for the performance and emission characteristics of a single cylinder direct injection diesel engine fuelled with Manilkara Zapota methyl ester and pure diesel blends that reveals as far as performance characteristics are concerned B20 performed well, whereas emission parameters are concerned B30 exhibited improved results [12]. 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 [13]. 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 [14]. Abedin M. J. 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 [15]. 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 [16]. 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 [17]. 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 [18]. 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 [19]. Banapurmath and Tewari (2008) have studied the performance and emission characteristics of a thermal barrier coated (Zirconia) diesel engine at constant speed with honge oil and its methyl ester with optimized injection timing as 19^0CA BTDC and at full load it has been reported that, the BTE and BSFC were improved as that of base engine [20]. Hanbey Hazer (2009) who studied the performance characteristics of a ceramic coated (MgO-ZrO2) diesel engine using canola methyl ester blends at different speeds at full load. It has been reported that the brake thermal efficiency of the engine is increased about 3.5% and the BSFC decreases 8% for alternative fuels [21].

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 modifying injection pressure, injection temperature, preheating of fuel and air, doping with nanoparticles, and thermal barrier coatings etc., 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. Therefore, in the present study Cymbopogon oil (Lemongrass oil) methyl ester was chosen as a fuel, because less research was observed with this biodiesel in modified engine, 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 Cymbopogon oil 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

Cymbopogon crude oil was purchased from lemongrass oil extraction plant, which is located at Khambhampadu near

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 05, May-2020

Tiruvuru, Andhra Pradesh State. The Cymbopogon crude oil is subjected to transesterification in our laboratory as follows,

Crude Cymbopogon oil is measured 1000 ml and is taken in a round bottom flask,12 grams of potassium hydroxide as an alkaline catalyst (KOH) is weighed and 250 ml of methyl alcohol is taken in a beaker. First of all, KOH is mixed with the alcohol and it is stirred until they are properly dissolved with each other. Then the crude Cymbopogon 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 Cymbopogon oil reaches 60^0c the KOH-Alcohol solution is poured into the crude Cymbopogon 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 Cymbopogon 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., Cymbopogon 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 Cymbopogon biodiesel which readies for use. The transesterification process was depicted in the Figure 1.

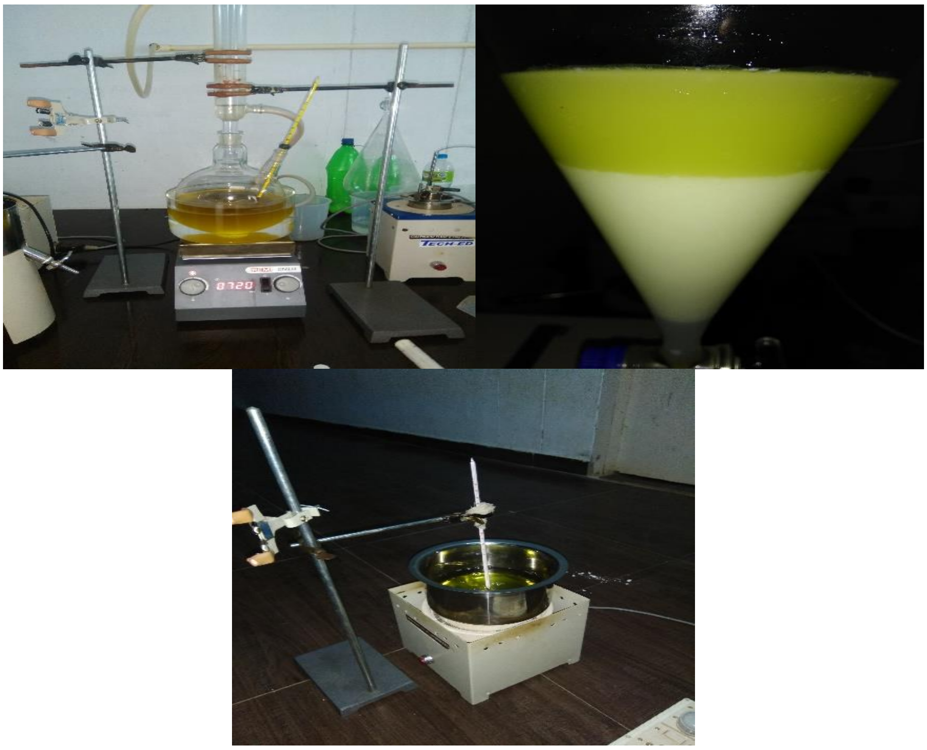

Figure 1. Transesterification Process

B. Preparation of Biodiesel-Diesel blends

Cymbopogon methyl ester and pure diesel blends were prepared for 500 ml quantity, firstly by mixing 50 ml of Cymbopogon methyl ester into 450 ml of pure diesel with the aid of magnetic stirrer for 5-10 minutes, and it was labeled as CME10D90 briefly B10, and same procedure was followed to prepare another two blends and were labeled as CME20D80 briefly B20, and CME30D70 briefly B30. The test samples were shown in the Figure 2, and the Corresponding physicochemical properties of fuel samples CME, B10, B20, and B30 were shown in the Table 1.

Table 1. Physicochemical Properties of Fuel Samples

Fuel Property	Diesel Specifications ASTMD975	Biodiesel Specifications ASTMD6751	CME	CME10D90 (B10)	CME20D80 (B20)	CME30D70 (B30)
Density (kg/m^3)	840	810 – 900	874.4	818.4	825.4	828.6
Kinematic Viscosity (mm^2 / Sec) @ 40^0c	3.8	1.9 – 6.0	4.17	2.68	2.81	2.94
Flash Point (^{0}c)	60	≥ 130	144	54	56	58
Cetane Index	47	38 min.	47.79	55.39	55.24	55.09
Calorific Value (KJ/Kg)	42,500	35,000 min	37,908	41,726	41,427	41,127

Figure 2. Test Samples

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 Cymbopogon 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.

Figure 3. Piston before coating and after coating

D. Experimental Setup

The present study was carried out to find the influence of Cymbopogon methyl ester blends such as CME10D90 (B10), CME20D80 (B20), and CME30D70 (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 [3,6,12]. 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 4. Photographic View of Experimental Setup [3,6,12]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 05, May-2020

Table 1. Specifications of the Experimental Setup [3,6,12,]

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 to be used

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 in 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

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, CME10D90 (B10) with coated engine registered lowest BSFC amongst all and it was improved by 5.88% compared to pure diesel and by 3.61% 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 CME10D90 (B10) 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, CME10D90 (B10) with base engine has recorded 34.57% of BTE and with coated engine has recorded 35.97% BTE, therefore for coated engine the BTE of CME10D90 (B10) was increased by 7.69% compared to pure diesel and by 4.05% compared to base engine data.

Figure 7. depicts the variation of total fuel consumption in kg/hr (TFC) 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 CME10D90 (B10) with coated engine was improved by 3.91% compared to CME10D90 (B10) with base engine and by 6.12% compared to pure diesel.

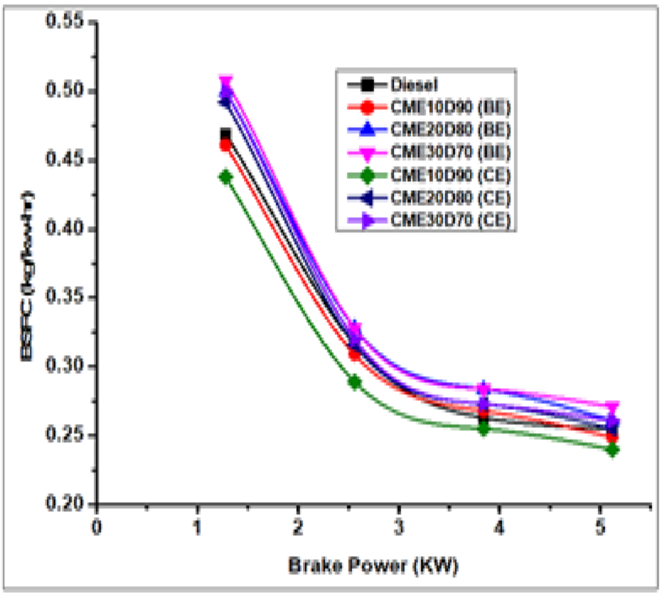

Figure 5. BP Vs BSFC

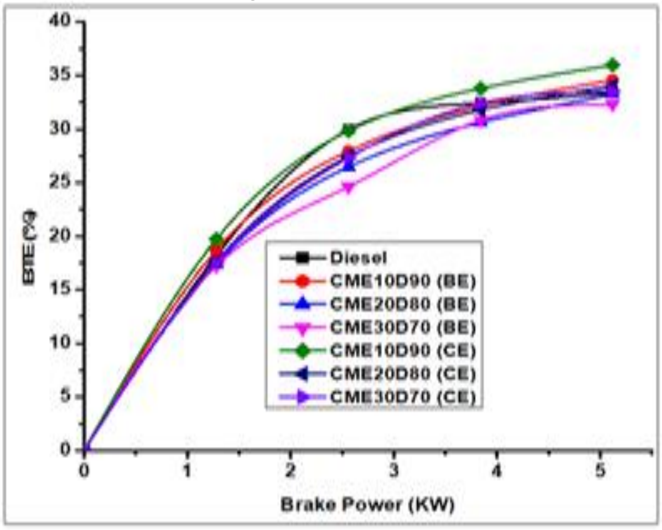

Figure 6. BP Vs BTE

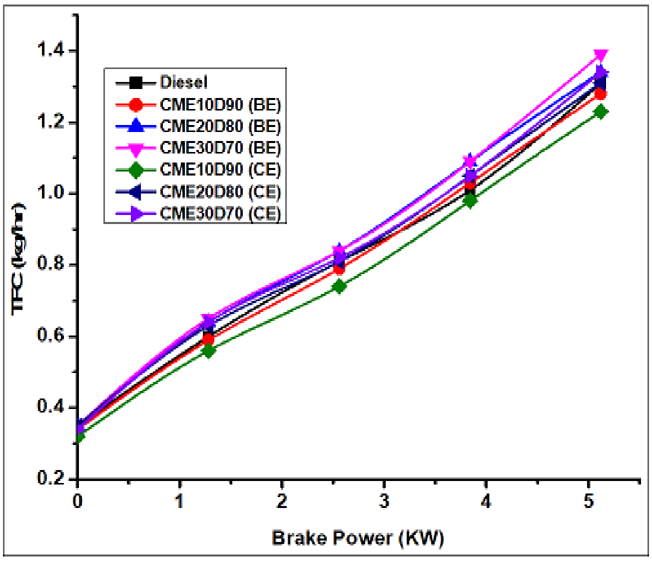

Figure 7. BP Vs TFC

IV. CONCLUSIONS

The performance characteristics of compression ignition engine powered with conventional diesel, diesel and biodiesel blend were investigated with and without piston coating. The conclusions of this investigation at full load condition are as follows,

- In general, the brake specific fuel consumption decreases with increase in load on the engine, among all the blends, CME10D90 (B10) with coated engine registered lowest BSFC amongst all and it was improved by 5.88% compared to pure diesel and by 3.61% compared to base engine data.
- Diesel has recorded 33.40 % of BTE, CME10D90 (B10) with base engine has recorded 34.57% of BTE and with coated engine has recorded 35.97% BTE, therefore for coated engine the BTE of CME10D90 (B10) was increased by 7.69% compared to pure diesel and by 4.05% compared to base engine data.
- Among all the blends, CME10D90 (B10) with base engine has registered 76.11%, CME10D90 with coated engine has recorded 76.45% and diesel has recorded 75.44%. Therefore, finally the mechanical efficiency of CME10D90 (B10) with coated engine was merely increased by 0.45% compared to base engine data, and slightly increased by 1.34% compared to pure diesel.
- The TFC of CME10D90 (B10) with coated engine was improved by 3.91% compared to CME10D90 (B10) with base engine and by 6.12% compared to pure diesel.
- The volumetric efficiency of CME10D90 (B10) with coated engine is lower than that of CME10D90 (B10) with base engine by 1.20% and decreased by 1.33% compared to pure diesel.

From the above conclusions it can be noticed that, as far as the performance parameters such as BSFC, BTE, Mechanical Efficiency and TFC, are concerned, out of all the blends CME10D90 (B10) 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.

REFERENCES

[1]. M. Vijayakumar and P. C. Mukesh Kumar. Performance and emission characteristics of compression ignition engine handling biodiesel blends with electronic fumigation. Heliyon 5 (2019) e01480. doi: 10.1016/j.heliyon.2019. e01480

[2]. Ganapathy T, Gakkhar R. P, and Murugesan K, Influence of Injection timing on Performance, Combustion and Emission Characteristics of Jatropha Bio-diesel engine, Applied Energy, (2011) doi:10.1016 / J. apenergy.2011.05.16

[3]. Nambaya Charyulu Tatikonda and P. Naveenchandran, The Behaviour of a Compression Ignition Engine Under the Influence of Diesel and Microalgae Biodiesel Blends, International Journal of Mechanical and Production Engineering, Research and Development, 9(4), 447-456 (2019), doi:10.24247/ijmperdaug201944

[4]. Avinash Kumar Agarwal, Atul Dhar, Karanja Oil Utilization in a direct-injection engine by Preheating. Part 1: Experimental investigations of engine Performance, Emissions and Combustion Characteristics, Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering 224(1), 73-84 (2010), doi:10.1243/09544070JAUTO1266

[5]. Deepak Agarwal and Avinash Kumar Agarwal, Performance and emission characteristics of Jatropha oil (Preheating and blends) in a direct injection compression ignition engine, Applied Thermal Engineering 27, 2314-2323 (2007), doi:10.1016/j.applthermaleng.2007.01.009

[6]. Nambaya Charyulu Tatikonda, and P. Naveenchandran, 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, International Journal of Engineering and Advanced Technology, 8(6), 3284-3290 (2019), doi:10.35940/ijeat. F9500.088619

[7]. Agarwal A. K, and L.M. Das, Bio-diesel development and characterization for use as a fuel in compression ignition engines, Journal of engineering for Gas Turbine and Power Transactions, ASME 123, 440-447 (2001), doi: 10.1115/1.1364522

[8]. G. Vinoth and P. Balaguru, Study and Performance analysis of biofuel (Lemongrass oil) by varying injection pressures, International Research Journal of Engineering and Technology, 6(6), 738-747 (2019)

[9]. T. Nambaya Charyulu, P. Naveenchandran, E. Raja and R.N. Babu, The Behavioural Attributes of a compression ignition engine powered with diesel and Artocarpus Heterophyllus methyl ester blends, Rasayan Journal of Chemistry, 13(2), 876-886 (2020), doi:10.31788/ RJC.2020.1325560

[10]. Ashok Kumar Jalasutram, B. Kiran Babu, CH. Venkata Krishna, and Ramakrishna Mekala, Combustion Phenomena, Emissions and Performance Characteristics of Lemongrass oil in Direct Injection (DI) Compression Ignition Diesel Engine, International Journal of Recent Technology and Engineering, 8(2), 2380-2386 (2019), doi: 10.35940/ijrte.A3382.078219

[11]. Venugapal V., Manjunath H.N., Rukmangadha P., and Dr. Madhu D., Experimental Investigation of Performance and Emission Characteristics of Lemongrass oil as Fuel, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11(4), 126-129 (2014)

[12]. Nambaya Charyulu Tatikonda and P. Naveenchandran, The Experimental Features of a Compression Ignition Engine Running on Pure Diesel and Mixtures of Diesel and Manilkara Zapota Methyl Ester, International Journal of Innovative Technology and Exploring Engineering, 8(11), 834(2019), doi: 10.35940/ijitee.K1499.0881119

[13]. Vinay Kumar Domakonda, and Ravi Kumar Puli, Application of Thermal Barrier Coatings in Diesel Engines: A Review, Energy and Power, 2(1), 9-17 (2012), doi: 10.5923/j.ep.20120201

[14]. Aydin, H.., Combined effects of thermal barrier coating and blending with diesel fuel on usability of vegetable oils in diesel engines., Applied Thermal Engineering, 51(1-2), 623–629 (2013) doi: 10.1016/j.applthermaleng.2012.10.030

[15]. Abedin, M. J., Masjuki, H. H., Kalam, M. A., Sanjid, A., and Ashraful, A. M., Combustion, performance, and emission characteristics of low heat rejection engine operating on various biodiesels and vegetable oils., Energy Conversion and Management, 85, 173–189 (2014). doi: 10.1016/j.enconman.2014.05.065

[16]. Aydin, S., Sayin, C., and Aydin, H., Investigation of the usability of biodiesel obtained from residual frying oil in a diesel engine with thermal barrier coating, Applied Thermal Engineering, 80, 212–219 (2015), doi:10.1016/j.applthermaleng.2015.01.061

[17]. Karthickeyan, V., Balamurugan, P., and Senthil, R., Comparative studies on emission reduction in thermal barrier coated engine using single blend ratio of various non-edible oils, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 39(5), 1823–1833 (2016), doi:10.1007/s40430-016-0645-0

[18]. Karthickeyan, V., Impact of partially stabilized zirconia on a single-cylinder diesel engine's performance, using orange oil methyl ester biodiesel, International Journal of Ambient Energy, 1–10 (2017), doi:10.1080/01430750.2017.1341429

[19]. Selvam M., Shanmugan S., and Palani S., Performance analysis of IC engine with ceramic-coated piston, Environmental Science and Pollution Research, 2018, doi: 10.1007/s11356-018-3419-7

[20]. N. R. Banapurmath and P. G. Tewari, Performance of a low heat rejection engine fuelled with low volatile Honge oil and its methyl ester (HOME), Proc. IMechE Vol.222, Part A. Journal of power and energy, 323-330 (2008), doi:10.1243/09576509JPE514

[21]. Hazar, H., Effects of biodiesel on a low heat loss diesel engine. Renewable Energy, 34(6), 1533–1537 (2009). doi:10.1016/j.renene.2008.11.008