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Effect of cadmium oxide nanoparticles on the performance characteristics of a compression ignition engine fuelled by microalgae methyl ester at 30% with pure diesel

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ABSTRACT
To improve the performance of compression ignition engine we can use some additives in biodiesel owing to its potential advantage of high surface area to volume ratio, and acting as a catalyst for better combustion. The current work deals with the experiments carried out to analyze the effect of cadmium oxide nanoparticles on the performance characteristics of a single-cylinder four-stroke compression ignition engine using microalgae methyl ester (MME)-pure diesel blend (B30) dispersed with cadmium oxide nanoparticles in the mass fractions of 50ppm, 100ppm and 150ppm with the aid of an ultrasonicator. Firstly, crude microalgae oil was transesterified into microalgae methyl ester, secondly, the blend was prepared by mixing 70% of pure diesel and 30% of microalgae methyl ester (B30) using a stirrer, then this blend was dispersed with cadmium oxide (CdO) nanoparticles in three proportions thereby designated as B30NP50, B30NP100, and B30NP150. Experiments were conducted and comparisons of diesel, B30 fuel with, and without CdO additives are presented. Finally, the experimental results revealed that, at full load condition, the BSFC, BTE, and TFC of B30NP150 were improved by 10.59%, 11.34%, and 10.69% compared to pure diesel

***Keywords* -** Cadmium Oxide Nanoparticles, Dispersion, Microalgae Crude Oil, Microalgae Methyl Ester, Performance and Fuel Economy Characteristics, Transesterification, Ultrasonicator

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I. INTRODUCTION

Diesel fuel has an important function within the industrial economy of a developing country and used for transport of commercial and agricultural goods and operation of diesel tractors and pump sets in the agricultural sector. The need for Petro diesel in India is predicted to grow from 39.815 MMT in 2001-02 to 52.324 MMT in 2006-07, just over 66 MMT in 2011-12, and 210 MMT in 2017-18. The domestic supply of petroleum will satisfy only about 22% of the demand and therefore the rest will need to be met from imported crude. It is expected by 2040 that, half of the global energy demand will be accomplished only by renewable sources [1]. This has stimulated recent interest in alternative sources to replace petroleum-based fuels. Among the alternative fuels, bio-diesel obtained from vegetable oils holds good promises as an eco-friendly alternative to diesel oil. Vegetable oil is a promising alternative fuel for CI engine because it is renewable, environment friendly and can be produced in rural areas. The utilization of non-edible vegetable oils compared to edible oils is extremely significant in developing countries due to the tremendous demand for edible oils as food and that they are too expensive to be used as fuel at the present. To understand the present scenario about biodiesel utility and its related issues an in-depth literature survey has been administrated, this review highlights the various issues associated with biodiesel like performance and emission characteristics etc., when it is used as a substitute fuel for unmodified and modified compression ignition engines.

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 [2]. 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 [3]. 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 [4]. 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 [5]. 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 [6]. 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 [7]. 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 [8]. Nambaya Charyulu Tatikonda, P. Naveenchandran (2019) investigated the behaviour a compression ignition engine under the influence of microalgae methyl ester 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 [9]. Siva Kumar et. al (2017) stated in their review that, by adding the nanoparticles either in diesel or biodiesel improves the engine performance and reduces emissions of diesel engine [10]. The experimental work of Bose Narayanasamy and Nagarajan Jeyakumar (2018) revealed that, the brake specific fuel consumption and the brake thermal efficiency of diesel engine were improved with TiO_2 nanoparticles dispersed with Azolla algae methyl ester and diesel blend [11]. Vijayan Venkatraman et. al (2018) experimentally commented on the effect of nanoparticles on the CI engine performance and emissions that, the use of zirconium oxide nanoparticles with Azolla algae biodiesel exhibits a significant reduction in emissions [12]. Tayfun Ozgur et. al (2015) have reported the results of their investigation on the effect of MgO and SiO_2 nano additives added in rapeseed biodiesel that, the engine emissions were decreased and the performance values are slightly increased [13]. C. Srinidhi et. al (2019) have found higher brake thermal efficiency at 27^0bTDC, during a test on VCR engine with Azadirachta indica biodiesel and pure diesel blend added with NiO nanoparticles at various injection timings [14]. Sumita Debbarma and Rahul Dev Misra (2018) evaluated the stationary diesel engine for performance and emission characteristics powered with palm biodiesel and pure diesel blend added with iron nanoparticles and claimed that brake thermal efficiency was increased by 2.06% and brake specific fuel consumption was reduced by 2.71% [15].

The above studies reveal that the diesel-biodiesel blends can be used as alternative fuels for diesel engines. Recent research has shown that the use of diesel biodiesel blends can substantially increase engine performance and reduce emissions. They had also suggested some alternative fuels which are friendly to the atmosphere. Therefore, in the present study Microalgae methyl ester at 30% was chosen as a fuel, because in the previous research [1, 9] microalgae methyl ester blended with pure diesel at 30% showed better performance characteristics than that of pure diesel, and Cadmium oxide nanoparticles were picked as additives as these are not found so far in the past research, So, the present work has found the research gap in this area and it reveals the performance characteristics of a compression ignition engine when it was run with the blend(B30) of diesel and microalgae methyl ester doped with cadmium oxide nanoparticles at 50 ppm, 100 ppm, and 150 ppm.

II. MATERIALS AND METHODS

A. Preparation of Biodiesel

Microalgae crude oil was purchased from biodiesel producers of Chidambaram, in Tamil Nadu 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 [1, 9]. 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 [1, 9]. Microalgae methyl ester and pure diesel blend (B30) was prepared by mixing 300ml of microalgae methyl ester into 700ml of pure diesel with the aid of magnetic stirrer.

B. Preparation of Biodiesel-Diesel blends

In the present study, commercially available cadmium oxide (CdO) nanoparticles with an average particle size of 20-30 nm were procured from the Nano Research Lab, Jharkhand. The nanoparticles with a mass fraction of 50 ppm are weighed and dispersed into microalgae methyl ester and diesel blend (B30) with the help of an ultrasonicator. The ultrasonication process was performed at a frequency of 20 kHz for 30 minutes duration. The ultrasonication process was shown in Figure 1. The prepared sample was named as MME30D70NP50 (B30NP50). The same procedure is continued for another two mass fractions of 100 ppm and 150 ppm and they were named as MME30D70NP100 (B30NP100), and MME30D70 NP150 (B30NP150) respectively. The test samples were shown in the Figure 2, and the Corresponding physicochemical properties of fuel samples B30, B30NP50, B30NP100, and B30NP150 were shown in the Table 1.

Figure.1 Ultrasonication Process

Figure.2 Test Samples

C. Experimental Setup

The present study was carried out to find the influence of microalgae methyl ester blend doped with Cadmium Oxide nano additives such as MME30D70NP50 (B30NP50), MME30D70NP100 (B30NP100), and MME30D70NP150 (B30NP150) on the performance of a direct injection compression ignition and compared with that of diesel fuel performance from no load to full conditions. 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 [1, 9]. 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 3.

Table 1. Physicochemical Properties of Fuel Samples

Fuel Property	Diesel Specifications ASTMD975	Biodiesel Specifications ASTMD6751	B30	B30NP50	B30NP100	B30NP150
Density (kg/m^3)	840	810 - 900	829.4	829.6	830.6	831.6
Kinematic Viscosity (mm^2 / Sec) @ 40^{0}c	3.8	1.9 – 6.0	3.11	-----	-----	-----
Flash Point (^{0}c)	60	≥ 130	58	-----	-----	-----
Cetane Index	47	38 min.	55.06	-----	-----	-----
Calorific Value (KJ/Kg)	42,500	35,000 min	41,291	41,591	41,789	41,915

Figure.3 Photographic View of Experimental Setup [1]

Table 2. Specifications of the Experimental Setup [1, 9]

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

D. Experimental Procedure

Firstly, allow 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%) note down the readings of performance parameters at each load. Secondly, power the engine with B30 and repeat the experiment, and thirdly, run the engine with B30NP50, B30NP100, and B30NP150 and revise the experiment at varied loads as well as record the performance readings. Finally, the experimental results to be analyzed and discussed.

E. 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

Fig. 4 conveys the variation of brake specific fuel consumption (BSFC) with brake power (BP) for all the test samples such as pure diesel, B30, B30NP50, B30NP100, and B30NP150 from zero to 100% load conditions. From the figure it was observed that, the fuel consumption of all the test samples has been reduced with an increase in the brake power. Brake specific fuel consumption is that the measure of how the supplied fuel energy to the engine is converted into brake power and it is often defined as the amount of fuel consumed in unit time for generating kw power. The experimental result revealed that the brake specific fuel consumption of doped biodiesel was improved compared to mineral diesel and B30 (MME30D70). This is due to the reason that, nanoparticles dispersed fuel possesses better atomization and combustion characteristics, and also nanoparticles reduce the formation of carbon deposits inside the combustion chamber which results in complete combustion. In the end, it could be confirmed that at maximum load condition, the BSFC of the blend MME30D70NP150 (B30NP150) was improved by 10.59% and 4.60% when compared to pure diesel and B30 respectively.

Fig. 5 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 slightly increased as the proportion of nanoparticles increased in the biodiesel compared to mineral diesel and B30. This is due to the fact that, encapsulation of nanoparticles in biodiesel provides reduced ignition delay, high evaporation rate, prolonged flame sustenance and higher flame temperature these are all leads to improve thermal efficiency. At maximum load condition, the BTE of MME30D70NP150 (B30NP150) is 37.67% and it was higher than B30 by 3.48% and higher than mineral diesel by 11.34%.

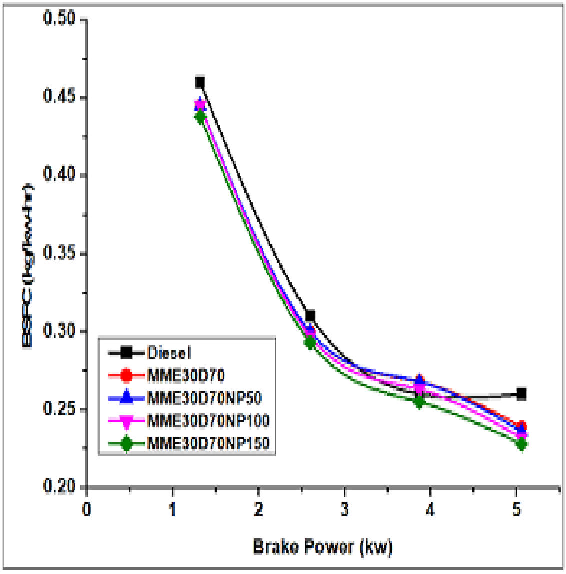

Figure. 4 BP Vs BSFC

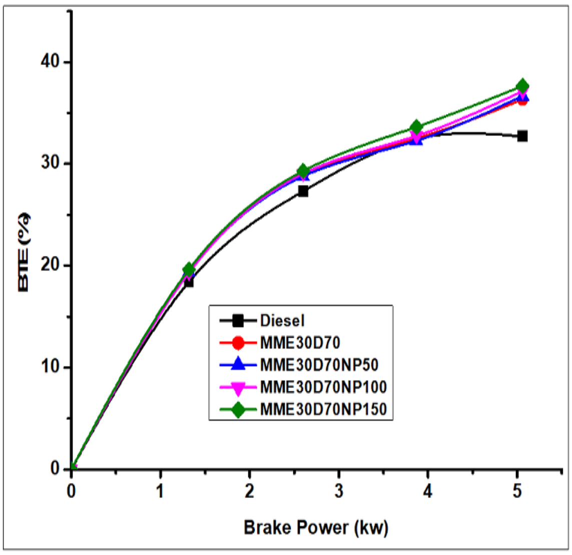

Figure. 5 BP Vs BTE

Fig. 6 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 an increase in brake power but at every load nano doped biodiesel has registered low TFC compared to pure diesel and B30. This is because, as the mass fraction of nanoparticles dispersed in the sample increases, it increases the better atomization and better mixing of fuel with air causing improved combustion. Finally, it was shown at full load condition that, the TFC of MME30D70NP150 (B30NP150) was improved by 3.25% compared to B30 and by 10.69% compared to pure diesel.

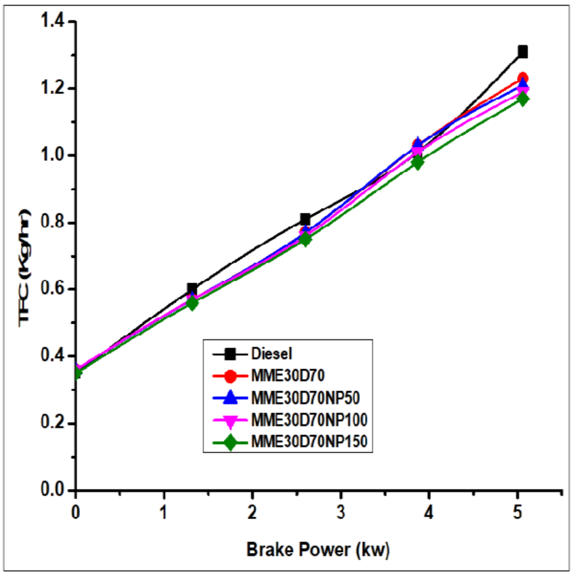

Figure. 6 BP Vs TFC

IV. CONCLUSIONS

The performance characteristics of compression ignition engine powered with conventional diesel, diesel, and biodiesel blend (B30) and doped diesel and biodiesel blends (B30NP50, B30NP100, and B30NP150) were investigated, and the final conclusions of this investigation at full load condition were reported as follows,

- In general, the brake specific fuel consumption decreases with an increase in load on the engine, among all the blends, B30NP150 takes less fuel consumption per kW-h power produced, and it was improved by 10.59% and 4.60% when compared to pure diesel and B30 respectively.
- The brake thermal efficiency increased with an increase in nanoparticle percentage. Out of all the blends, B30NP150 shows the best performance parameters. The BTE of B30NP150 is 37.67% and it was higher than B30 by 3.48% and higher than mineral diesel by 11.34%.
- The total fuel consumption of B30NP150 was improved by 3.25% compared to B30 and by 10.69% 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 of doped microalgae methyl ester at 150 ppm (B30NP150) was concluded as the optimum blend. In the future, this experimentation can be extended to find out the emission and combustion characteristics of the same engine when it is fuelled with the same doped blends.

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