Performance and Emission Characteristics of Four Stroke Diesel Engine Using Sesame Biodiesel Blends with Addition of TiO$_2$ Nano-Particles

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Abstract. Rising demand for fuel in various applications will now pose a major risk in terms of global emissions levels. Taking this issue into consideration takes significant attention. Hence the production of alternating fuels is required. Bio-diesel is environmentally friendly fuel consisting of fatty acid alkyl esters. This experimental study includes a comparative analysis to determine the effect of nano additives and their performance characteristics. The theme of the research is the combination of sesame oil biodiesel with titanium dioxide (TiO$_2$), a metal-based nanoparticle with diesel to investigate its effects on the performance of diesel engines. Different fuel blend ratios with TiO$_2$ nanoparticles, ethanol and biodiesel have been developed. Test fuels were diesel (D100) and biodiesel blends like B10, B20 and B30. Thermo-physical characteristics of all test fuels have been calculated and the engine output parameters, such as torque, power, fuel consumption, etc., were examined. The impact has also been realized on pollutants such as CO, CO$_2$, HC, NO$_X$ and smoke ability.

Keywords: Emission and combustion, Diesel engine, Performance, Sesame oil methyl ester.

1. Introduction

The key alternative source of energy is bio-fuels, since they are sustainable, organic and environmentally friendly. It can be obtained from various organic products, like mahua, jatropha, coconut, and vegetables, etc. Which is safe, non-combustible, harmless, environmentally friendly biofuel and bio-degradable without harm to the environment in the soil. Supplier emissions are also cleaner and lower from diesel. [1]. Biodiesel is a source of renewable energy which can help reduce greenhouse gas emissions. It does little towards support increasing of earth’s environmental temperature, since plant feedstock has extracted carbon from the environment [11]. Bio-fuels are mostly used as fuel for transport. Over the past decade, global bio-fuel production has steadily grown from 16 billion liters in 2000 to around 110 billion liters. Biodiesel fuels can be used without engine changes in standard diesel cars. With better lubrication properties and significantly lower emissions than those of today low-sulphur diesel fuels, biodiesel is an environmentally sustainable source of
renewable energy [2]. In addition, biodiesel reduces fuel system wear and enhances the life of fuel injection equipment that relies on low-pressure lubricating fuel in high-pressure systems. Biodiesel generates more total combustion, thereby increasing the performance of engine power and partly offsetting the higher energy density of petro-diesel. The growing industrialization of petroleum products worldwide tends to a sharp increase in requirement. Terrestrial fuels are considered fossil fuels. These stored fuels have, and are irreplaceable, a limited quantity of fuel. With our current known reserves and rising consumption rates, it is thought that they will not last long [2]. In some areas of the world, these small supplies of petroleum are highly oriented, causing often disruption and instability in both their supply and price. Although the current reserves seem immense, growing consumption will create a challenge for the world to replace fossil fuels with a new type of fuel. Under cold conditions; biodiesel performance is slightly lower than petroleum diesel performance, for biodiesel, the cloud and pour points are larger than for diesel oil. There are mainly classified into three generations:

1.1 First generation

Using traditional technologies, sugar, starch, vegetable oil or animal fats are used to produce biofuels. These are typically derived from grains high in sugar or starch fermented with bioethanol; or from seeds pressed with vegetable oil from biodiesel [15]. Biodiesel, bio-alcoholics, biogas and solid biofuels, vegetable oils, are all bio-fuels of the first generation.

1.2 Second generation

Biofuels are derived from non-food crops such as celluloid biofuels and waste biomass. Work continues on bio-fuels of the second generation, including bio-hydrogen, bio-methanol, bio-hydrogen diesel and mixed alcohol [7].

1.3 Third generation

Bio fuels are derived from the extraction of algae oil—also known as high yield “oilgae.” Its production can be low cost.

Rising oil prices demand a report on biodiesel production. In India’s industrial economy diesel fuels have an important role to play. The supply of fossil fuels is decreasing rapidly due to rising energy demand in the developing world, and the growing use of fossil fuels. Some alternative diesel fuel options usually include various vegetable oils, biogas producer gas and methanol, and ethanol. One of the Diesel engine's capable alternative fuels is from this sesame oil [30]. Sesame oil is a non-conventional, non-toxic, cheap and low-grade vegetable oil that can be produced from agricultural and plant resources locally. Their consumption is not associated with detrimental effects on the environment, since they produce less toxic emissions and greenhouse gases. The edible vegetable oil extracted from sesame seeds is sesame oil. In addition to being used as cooking oil, it is often used in many cuisines as a flavour enhancer. Sesame seed contains 50-60 percent high-quality oil rich in polyunsaturated fatty acids shown in Table1: (PUFA) and natural antioxidants, sesame and sesamoline. These bioactive components strengthen the stability and consistency of sesame oil along with many health benefits. The sesame seeds also contain two special substances, sesame and sesamoline, in addition to these basic nutrients. Both of these substances belong to a group of unique beneficial fibers called lingams, which have a diminishing effect of cholesterol in humans, preventing high blood pressure which increases vitamin E supplies in animals. Mass production of sesame oil is limited worldwide due to inefficient manual harvesting process needed to extract the oil.
Sesame oil is naturally light yellow in colour and is used in the manufacture of medicines as a solvent, and also in the preparation of soaps, paints, lubricants.

| Name of Fatty Acid | Formula       | % by Weight |
|-------------------|---------------|-------------|
| Linoleic acid     | C18H32O2      | 41          |
| Oleic acid        | C18H34O2      | 39          |
| Palmitic acid     | C16H32O2      | 8           |
| Stearic acid      | C18H36O2      | 5           |
| Others            | -             | 7           |

I. Ors, S. Sarkoc et al. [1] Observed effects on performance, combustion and emission characteristics of the Direct Injection Compression Ignition engine fuelled with TiO$_2$ nano-particles applied to diesel, biodiesel and n-butanol blends. Diesel, biodiesel (B100), B20, B20 + TiO$_2$ were used as test fuels. The addition of n-butanol to the fuel introduces density, kinematic viscosity and cold flow properties that have been greatly affected, though adding TiO$_2$ has little effect on these properties. Homa Hosseinzaadeh-Bandbafha et al. [2] Effects of water-emulsified oil, biodiesel mixtures have been observed on the performance and emission parameters of the aqueous carbon nano-particle diesel engine as a novel nano-additive. Various sizes (38, 75 and 150μm) of nano-additive fuel mixtures were combusted under four separate engine loads varying from 25 to 100 percent of the full load conditions in a diesel engine at a set engine speed of 1000 rpm. The most desirable performance characteristics were observed for the emulsified fuel mixture containing 38 μM carbon nano particles, which improved the brake power and thermal brake efficiency by 1.07 kW and 11.58 percent respectively, at full load operation, the brake specific fuel consumption decreases by approximately 107.3 g / Kwh. K. Kannan and Marappan [3] Efficiency and emission characteristics of the diesel engine checked with THEVETIA PERUVIANA Diesel and Diethyl Ether mixes 5 percent, 10 percent, 15 percent and 20 percent. It has been found from the comprehensive analysis that 20 percent DEE blend will result in a 5 percent rise in full-load biodiesel blend, a 14.63 percent reduction in harm smoke quality. It was concluded that better results would benefit from a 20 percent blend. Subrahmanyam. J. P et al. [4] Investigated the combustion and emission characteristics of the diesel engine using karanja oil methyl ester (KOME) blend in the 5 percent, 10 percent, 15 percent and 20 percent ratio with Di ethyl ester. Brake thermal efficiency with 15 percent KOME blend improved by 5.5 percent. Smoke opacity decreased to a minimum maximum load level with a 20 percent KOME- DEE blend. The optimum blend based on emission and efficiency characteristics was found to be the 15 per cent KOME DEE from the various KOME-DEE blend studies. V. Rambabu [5] Researched DI Diesel Engine’s efficiency, emission, and combustion characteristics along with Methanol Carburization with Linseed methyl ester. The findings and study of the 1/32$^{th}$ throttle valve opening (3.73% of Methanol at maximum load) along with Bio-diesel activity provide improved thermal efficiency (23.546%) and low pollutants such as CO and HC. K. PrasadaRao [6] The output features of the diesel direct injection engine were investigated along with Methanol Carburization using Mahua methyl ester. From this study efficiency and emission analysis, HC, CO pollutants can be found to be low in scarifying small quantities of Brake Thermal Efficacy. In other words, the process of biodiesel MME along with improved braking power at the 1/16th throttle valve release. Mithun Das et al. [7] The refined castor oil for the production of biodiesel was used with special methanol and sodium hydroxide parameters. For analysis, biodiesel blends such as B5, B10 and B15 were considered, and research was conducted on the porous sphere. Diesel displayed a high rate of evaporation and the findings showed the high chemical reactivity of biodiesel mixtures. They concluded that the limited use of biodiesel in the
blending of diesel biodiesel may help minimize reliance on fossil fuels. Nitin Shrivastava et al. [8] A 4-cylinder, 4-stroke, direct injection diesel engine with 50 and 150 gm / L alumina nano particles has been tested for Jatropha Oil Methyl Ester (JOME), resulted in the introduction in JOME of 50 and 150 mg / L nanoparticles, respectively, reducing BSFC by 9.1%, 12.2% (BTE). In JOME fuel, the same amount of nano particle addition was observed to increase by 2.4 percent and 6.2 percent. Reduces by 5.7 percent and 13.7 percent respectively the average HC emissions. In JOME fuel, The addition of 50 and 150 mg / L nanoparticles was demonstrated an average decrease of 8.4 percent and 16.7 percent in CO. JOME registered a reduction of 1.8 percent in NO\textsubscript{x} and 4.7 percent in NO\textsubscript{x} with the same amount of additional nanoparticles. Hossein Soukht Saraee et al. [9] For oil extracted from Pistacia Khinjuk using the SO\textsubscript{x} hlet extractor, a maximum yield of 35\text{to}40\ percent was demonstrated. For DI Diesel engine research and testing, fuel samples such as B5, B10, B20, B40 and B100 have been considered. Biodiesel samples revealed a greater fuel consumption than petrol. Biodiesel blends were discovered with lower CO and HC smoke concentrations.

2. Fuel preparation

Biodiesel is composed of monoester alkyl fatty acids. It is extracted through the transesterification process from the tri-glycerides. Transesterification is the term used to describe organic reactions as the main class in which, by the exchange of alkyl groups, an ester is converted into another ester and is often referred to as alcoholysis. Transesterification is a reaction to equilibrium, and by combining the reactants, the process occurs. However, the presence of a catalyst significantly speeds up the transition in equilibrium. The fatty acid radicals of the triglyceride molecule break free from glycerin bonds, and the fatty acid radicals build new ester ties with the alcohol molecules, resulting in glycerin and fatty acid-free esters. Straight-chain radical fatty acids are described in the details below.

Transesterification reactions between triglyceride and alcohol:

\[
\begin{align*}
\text{CH}_2\text{COOR}_1 & \quad \text{Catalyst} \quad \text{CH}_3\text{COOR}_1 & \quad \text{CH}_2\text{–OH} \\
\text{CHCOOR}_2 + 3 \text{CH}_3\text{OH} & \quad (\text{NaOCH}_3) \quad \text{CH}_3\text{COOR}_2 + \text{CH}_3\text{OH} \\
\text{CH}_2\text{COOR}_3 & \quad \text{Mixture of} \quad \text{CH}_3\text{COOR}_3 \quad \text{CH}_2\text{–OH} \\
\text{Triglyceride (Vegetable oil)} & \quad \text{fatty esters} \quad \text{Glycerin}
\end{align*}
\]

Preparing the biodiesel from sesame oil is performed in four steps.

2.1 Acidic Treatment

The process of transesterification of sesame oil was used directly to generate biodiesel from sesame oil because of the low acid value. During this process, with the help of a magnetic stirrer, the reactor was filled with 1 litre of refined sesame oil and heated to 60 °C for 10 minutes. Then, 250 ml of methanol was added to the sesame oil and added 2 - 3 ml of \text{H}_2\text{SO}_4 methanol- \text{H}_2\text{SO}_4 after sometime. The preheated oil was then added to mixture. The reaction then kept for 1.5 h at a steady stirring rate of 1500 rpm. If the reaction stops, after one hour of watching the solution, pulp will calm down.
2.2 Basic Treatment

After extracting the pulp from the solution, it brings the solution into the conical flask and stirs with heat and adds 250 ml of methanol to the acidic solution and then adds 7 grams of NaOH pallets to the SOLUTION at 45 °C after reaching a certain temperature. After the reaction was completed, almost all reaction products have been moved overnight to the separation funnel. To allow the separation of biodiesel from glycerine.

2.3 Water washing

Air agitation is used by the biodiesel final washing technique, the pH value of the oil no longer needs to be checked, as it is presumed that the biodiesel that comes out is essentially neutral. A third of the water is applied to the oil by volume and the bubble is cleaned to remove the bubbles. The mixture settles for one hour in a decanter, and then drains the water later.

2.4 De-hydration

After water washing, the method of dehydration is carried out to remove the traces of water left in the residual oil. The oil is arranged in a beaker and heated to a heater that includes a magnetic stirrer for continuous stirring in order to eliminate traces of water present in the oil. As the water evaporates at 100 °C, the oil is heated to more than 100 °C. After transesterification process the final Palm methyl ester (biodiesel) was obtained.
Using the ultrasonic Hielscher ultrasonic UP400S, 400 watts at a frequency of 34 kHz for half an hour, the titanium oxide nanoparticles were dispersed into biodiesel mixtures. Weighted the nanoparticles with a mass fraction of 25 mg and 50 mg / l. Nano-particles of titanium oxide occur in the form of hexagonal white crystals, or even in small particles. Due to its clarity and very high refractive index the primary application of TiO$_2$ is as a white powder pigment. It is used in products such as paints, coatings, cosmetics and pharmaceuticals etc.

| S.NO | Property          | Value      |
|------|------------------|------------|
| 1    | Density          | 4.23 gm/cm$^3$ |
| 2    | Molar mass       | 79.93 gm/mol |
| 3    | Melting point    | 1843$^\circ$C |
| 4    | Boiling point    | 2972$^\circ$C |

The sample is then tested for flash & fire point using the Cleveland apparatus and the calorific value by the bomb calorimeter.
### Table 3 Blended Diesel and Biodiesel properties

| S. No | Property         | Units       | Blended sesame | Biodiesel   |
|-------|------------------|-------------|----------------|-------------|
| 1     | Density          | kg/m³       | 830            | 870         |
| 2     | Specific Gravity | kg/m³       | 0.830          | 0.824       |
| 3     | Kinematic Viscosity | mm²/sec     | 4.4           | 5.9         |
| 4     | Calorific Value  | kJ/kg       | 45500          | 46509.42    |
| 5     | Flash point      | °C          | 75             | 184.6       |
| 6     | Fire point       | °C          | 80             | 189.6       |

The average calorific value for blended sesame bio-diesel is 11019.36 Kcal / kg. Thus, because 1 Kcal / kg = 4.18 KJ / kg, the calorific value = 46509.42 KJ / kg.

### 3. Experimental setup and procedure

Experiments have been performed on a Direct Injection Water cooled single-cylinder diesel engine with 4-stroke, the Table 4 indicates specifications of which are given. Figure 7 displays the schematics for the experimental set-up. To control the engine, a steady speed of 1500 rpm was used. Tests were carried on diesel engine by TiO₂ nano particulate substitute, Sesame oil. With load in 25 percent steps, from free load to full load. The motor was coupled to the electrical dynamometer to provide the brake load. For the diesel fuel and sesame oil, two different fuel tanks were used. For the volumetric fuel flow rate measurement, a 50 cm³ burette and a stop watch were used. Using the AVL-444 5 gas analyzer, emissions such as CO, HC and NOx were analyzed and smoke was measured by the Bosch smoke pump and the smoke meter is attached to the engine’s exhaust manifold.
Table 4 Specifications of test engine

| Engine                                | AV-I, Kirloskar |
|---------------------------------------|-----------------|
| Power (Kw)                            | 4.4             |
| Bore (mm)                             | 87.50           |
| Stroke (mm)                           | 110             |
| Compression ratio                     | 17.5:01         |
| Speed (Rpm)                           | 1500            |
| Injection pressure (Bar)              | 200             |
| Injection timing                      | 23° BDC         |

4. Results and discussions

4.1 Performance of the Engine

The intent of this study is to investigate the effects on engine performance parameters of brake torque, brake power (BP) and brake specific fuel consumption (BSFC), for which the metal based additives and oxygenated fuel mixtures are used.

The tests were performed at different engine speed levels’ using the fuel blends of D100, B100, B20, B20 + TiO₂. Both test results for obtained and fuel properties and as regards confirmations, they were compared with one another.

4.2 Brake power and Engine torque

Figures 8 & 9 display the performance at different engine speeds of both the torque of the brake engine and the power of the test fuel blends. Max values for torque of 34.73 N-m, 28.89 N-m, 32.49 N-m, 35.59 N-m, for D100, B100, B20, B20 + TiO₂, fuel blends respectively, were registered at 1400 rpm. The average brake torque values as compared with diesel for Blend100 and B20 decreased by approximately 21%, 6.61% respectively, while for B20 + TiO₂ they increased by approximately 2.89%.

![Figure 8](image_url)

Figure 8 At different engine accelerations and full load conditions, brake torque values

For fuel mixtures D100, B100, B20, B20 + TiO₂, the maximum brake power values are 8.86 Kw, 8.16 Kw, 6.47 Kw and 5.7 Kw, respectively, recorded at 2800 rpm. Brake torque and engine speed are directly correlated with engine brake power, since improvements in brake torque have a direct effect on engine brake power at the same engine rpm. It’s evident that the addition of TiO₂ to fuel mixes
significantly increases the torque and power values of the engine brake. Nano-particles are also a high proportion of surface-volume and have greater oxidation of the fuel mixtures.

![Figure 9 Brake power values and maximum load conditions at various engine speeds](image)

**4.3 Brake Specific Fuel Consumption (BSFC)**

Figure 10 indicates the difference in Brake Specific Fuel Consumption (BSFC) at different engine speeds. The lowest BSFC values for D100, B20, B100, B20 + TiO\(_2\) test fuels were 263.69 gr / Kwh, 271.99 gr / Kwh, 321.08 gr / Kwh and 250.18 gr / Kwh at 1800 rpm. Compared to euro diesel, B20 test fuels were 21.09 percent, 4.41 percent and 14.64 percent respectively, BSFC average increase for B100.

![Figure 10 Brake-specific fuel consumption values at various engine speeds and with maximum load conditions](image)

By comparison B20 + TiO\(_2\) BSFC decreased by 24.52 percent and 17.78 percent when adding TiO\(_2\). It is clear that the BSFC was greatly impacted by the inclusion of biodiesel and TiO\(_2\) in the fuel blends. The TiO\(_2\) additive was reduced to BSFC. This is due to the high surface area of TiO\(_2\), which, as a result of improved reaction surface area, leads to improved combustion efficiency.

**4.4 Exhaust emissions**

**4.4.1 CO emissions**

CO emissions Figure 11. The CO emissions outcomes are shown for both fully loaded test fuels and different engine speeds. Maximum values were registered for all fuel blends at 1000 rpm. Compared to diesel, B100, B20, B20 + TiO\(_2\) average CO emissions decreased by 44.83%, 16.51%, 25.56%, 27.44% and 38.09% respectively. B100 fuel obtains the lowest CO emission values. It is also noted
that the additive fuel blend B20 + TiO$_2$ reduced the value of CO emissions by approximately 10.86 percent compared to B20. This can be caused by the fact that the reaction surface area is increased by nanoparticles (TiO$_2$) and hence the combustion reaction is enhanced, leading to a decrease in the formation of CO.

![Figure 11 Values of CO emissions at different engine speeds](image)

4.4.2 CO$_2$ emissions
Max CO$_2$ emission values for all test oils, as shown in Figure.12, have been achieved at 2800 rpm and full load engine condition. Increased average CO$_2$ emission levels were 13.82 percent, 3.88 percent, 9.94 percent compared to Euro diesel for B100, B20, B20 + TiO$_2$ test fuels.

![Figure 12 CO$_2$ emission rates at varying engine speeds and under optimal conditions for charging](image)

The CO$_2$ emission values have raised by around 5.88 percent and 5.79 percent, respectively, compared to B20 and B20+TiO$_2$. Adding TiO$_2$ to fuel blend increases average values for CO$_2$ emissions. This can be explained by the fact that CO$_2$ formation is rising as CO emissions fall, nano particles improve the combustion mechanism in such a way that the CO and CO$_2$ formation equilibrium occurs.

4.4.3 HC emissions
Figure.13 shows HC emissions for all test fuel at full load engine condition and varying engine speeds. Maximum emission values for HC were reported at 1000 rpm. While minimum values for all fuel mixtures were obtained at 3000 rpm, except for Euro diesel. Average reduction in HC emissions for B100, B20, B20 + TiO$_2$ test fuels was approximately 45.14 percent, 29.58 percent, 34.12 percent.
HC emission values decreased by 6.33 percent and 22.38 percent relative to the fuel blend without additives (B20) and TiO$_2$ additives (B20+TiO$_2$).

![Figure 13 HC emission values and maximum load conditions at different engine speeds](image)

**Figure 13** HC emission values and maximum load conditions at different engine speeds

4.4.4 NO$_x$ Emissions

For all test fuels at full load and distinct engine speeds, the NO$_x$ emission results are shown in Figure 14. The maximum NO$_x$ emission values were recorded at 2800 rpm for all of the test fuels. Compared to euro diesel, the average rise in NO$_x$ values for test fuel B100, B20, B20 + TiO$_2$ was 18.90 percent, 4.73 percent and 11.99 percent respectively.

![Figure 14: Emission values of NO$_x$ at different engine speeds and ideal charging conditions](image)

**Figure 14**: Emission values of NO$_x$ at different engine speeds and ideal charging conditions

By the addition of TiO$_2$ (B20 + TiO$_2$ and B20) causes NO$_x$ emission values to increase by approximately 6.98 percent and 3.97 percent relative to B20 and certain fuel mixes. For B100, the highest NO$_x$ emission value was recorded, while for B20+TiO$_2$ fuel blends, the lowest value was recorded. However, the combustion is improved by the TiO$_2$ additive.

6. Conclusions and discussions

In this research, biodiesel derived from sesame oil was mixed in different ratios with Euro diesel and nanoparticles of TiO$_2$. Thermo physical and chemical properties, such as density, fire and flash points and kinematic viscosity have been calculated and the calorific value has been calculated for different blends. The engine performance, combustion analysis and exhaust emission parameters were investigated. The following findings can be given below on the basis of the results of this report:
Fossil-based production of biodiesel will greatly reduce the cost of manufacturing biodiesel. The properties of biodiesel follow specifications of both EN 14,214 and ASTM 6751. Thus, in diesel engines, biodiesel cooking waste may be used.

Maximum brake torque and power values were reported at 1400 rpm and 2800 rpm respectively for all tested fuels. Compared to the B20 blend, the addition of TiO$_2$ to the B20 increased the engine brake torque and power by about 10.22%. Additionally, the B20 + TiO$_2$ brake engine's torque and power is about 9.76 percent higher than the B20 blend. However, brake-specific fuel consumption decreased by 27.73 percent. It can be concluded that the engine output was positively affected by the TiO$_2$’s contribution to the fuel mixture.

The large nano-particulate surface area increases the reaction surface and the rate of heat transfer. The use of TiO$_2$ nano-particles in fuel mixtures has improved combustion during the combustion process due to a catalytic effect. As a result, the gross cylinder pressure and heat release rate for the TiO$_2$ additive are improved compared to Euro diesel.

Although CO emissions, HC emissions and smoke opacity of sesame oil biodiesel have decreased, compared to Euro diesel emissions, NOx and CO$_2$ emissions have increased.

Usage of TiO$_2$ nano-particles decreased emissions of CO, HC and smoke opacity. In comparison to fuel blends without TiO$_2$ additives, CO$_2$ and NOx emissions are improved in the combustion process.

It can be concluded that biodiesel derived from sesame oil and nano-particles derived from TiO$_2$ can be regarded as promising alternative fuels for diesel engines, in view of all these findings. The torque and performance of the brake engine are not only significantly improved by TiO$_2$ nano-particles, but also reduces the basic fuel consumption of the fuel mixtures. It also improves the combustion method and the emissions of CO, HC and smoke opacity that have been positively affected. Further studies of various engine loads in multi-cylinder CIDI diesel engines are therefore suggested with a view to making a stronger conclusion on the effect of the TiO$_2$ additive. Additionally, it is possible to investigate the effects of other nano-particles on engine efficiency, combustion, and emission properties.

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