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PERFORMANCE AND EMISSION CHARACTERISTICS ON DI-CI ENGINE FUELLED WITH BIO-DIESEL BLENDS DOPED NANOPARTICLES

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Abstract:

Increase in population and living standards of human beings will lead to an energy crisis. This leads to the faster depletion of fossil fuels. The fossil fuel is also a major contributor for this environmental degradation. This problem can be greatly reduced by fuel modification that improves performance, combustion and reduces emission characteristics. In the present investigation is carried out to establish the performance and emission characteristics of a DI CI engine while using cerium oxide (Ceria) and Aluminium oxide (Alumina) nanoparticles as additive in neat diesel and diesel-biodiesel blends at different loads at constant rated speed of 1500 rpm. The biodiesel is produced from the raw jatropha oil by standard transesterification process, and subsequently, the chemical nanoparticles are produced by chemical sol-gel process and blended with biodiesel blends with the aid of an Ultrasonicator. B20 is the best fuel ratio compared with other biodiesel-diesel blends. The experimental values of B20 doped with 25 ppm of ceria and alumina nanoparticles are compared with neat diesel and B20 doped with 25 ppm of ceria and alumina nanoparticles, the values of brake thermal efficiency 2.75%, exhaust gas temperature 2% are increased. CO, HC, CO_2, NO_x and smoke were 4.11%, 3.84%, 3.94% and 1.21% decreased. However, the smoke emission is 1.54% higher than that of diesel.

Key Words: Biodiesel, Jatropha Biodiesel, Nano Additives, Engine Performance & Emissions

1. Introduction:

Vehicular emission has grown at an alarming rate due to rising urbanization in the world. The air pollution from vehicles in urban areas, particularly in big cities, has become a serious problem [1]. Population growth has had a negative impact on the quality of the environment. Increasing human demand goes hand-in-hand with the more demand of resources to maintain the well-being of the population [2]. Due to recent energy and fossil fuel crisis, demand for diesel and other petroleum products increases with a rise of oil import by 92% in the year of 2030 [3]. In this increasing fuel demand, there is a necessity for an alternative fuel that should be easily available, environment friendly potential usage, biodegradable and contribution to sustainability [4]. With all these parameters, the best suited alternative fuel is "Bio-diesel" [5]. The Government of India has identified 98 million acres of land where Jatropha can be grown, hoping it will replace 20% of India's diesel consumption by 2021 [6]. When used directly used as a fuel in the engine, it causes problems like poor fuel atomization, incomplete combustion and carbon deposit formation, engine fouling and lubrication oil contamination [7]. To overcome the above problem, the oil is modified chemically by the transesterification process which is known as biodiesel.

2. Fuel Preparation & Properties:

Jatropha Biodiesel:

Jatropha oil and diesel were purchased from an open market. The raw jatropha oil was not directly added in the diesel engine as an alternative fuel. The fatty acids were highly reduced and transesterification processes were followed for the preparation of Jatropha biodiesel.

The two steps for the Jatropha biodiesel production are

- Reduction of the fatty acid contained in the Jatropha oil.
- Transesterification.

The step by step approach used in the production of the biodiesel by transesterification process is given below.

- 2400 ml of raw oil is filtered using cloth to remove and poured into biodiesel production unit in which 400 ml of methanol is used as a solvent.
- Raw oil is then heated up to 60°C for the production of methyl esters.
- Required amount of KOH pellets are weighed quickly and grinded to obtain the powder form. Powdered pellets are mixed into the solvent solution and mixed vigorously in a conical flask and it is found that methyl and ethyl esters are converted into ethoxide and methoxide.
- After reaction is completed, the product is allowed to settle overnight. Two different liquid phases are seen where crude esters are at the top and glycerol at the bottom which is called the transesterification process. Glycerol is removed as it settles down.
- Crude ester phase is separated and glycerol phase is then washed by warm de-ionized water and the excess methanol and water in the ester phase is removed by evaporation under atmospheric condition after being measured.

Cerium Oxide Nanoparticles (CeO_2):

There are many methods for the nano particles preparation, such as plasma arcing, sol-gel synthesis and ball milling process and so on. Several metals are known to catalyze combustion of hydrocarbon fuels. Among these, Cerium oxide tops the list because, cerium oxide acts as an oxygen donating catalyst and provides oxygen for the reduction of NO_x. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results in the reduction of HC emissions. In addition, break thermal efficiency increases

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simultaneously when due to this feature availing in the cerium oxide nanoparticles. Another major advantage of using CeO_2 is to decrease the ignition delay and it enhances combustion resulting in the reduction of smoke emission levels. Addition of Cerium oxide to diesel also accelerates earlier initiation of combustion and causes lower heat release rate when comparing with pure diesel. The relative air-fuel ratio is higher at lower BMEP and decreases as the BMEP increases. Under all loads, the addition of cerium oxide to diesel helps the engine to operate at lean mixtures than the neat diesel. It has more surface area, higher activity and can react with diesel at high temperature to generate hydrogen and improve fuel combustion; this chemical has been taken for the experimental investigation.

Fuel preparation:

In the first part of this work, the fuel samples of neat diesel, a blend of 20% jatropha biodiesel oil and 80% diesel by volume (B20) is taken as per many past investigations and publications and it has been proved that B20 blend is used for diesel engine without any engine modifications at the same time it reduces significantly the brake thermal efficiency of the engine to overcome the properties of B20 blends doped with cerium oxide and aluminium oxide nanoparticles. In the second part of the work, the fuel samples of B20 and B20 with 25 ppm of CeO_2 and Al_2O_3 were used. The chemicals needed for the preparation of Cerium oxide and Aluminium oxide nanoparticles were purchased from M/s. Sigma-Aldrich, USA and their detailed specifications are in the table 1.

Table 1: Specifications of Cerium oxide & Aluminium oxide nanoparticles

Compound Formula	**CeO_2**	**Al_2O_3**
Molecular Formula	172.12	101.96
Appearance	Brown to yellow	White powder
Melting Point	2340°C	2977°C
Density	7.6 g/cm3	0.2-0.4 g/mL at 25°C
Specific Heat	390 J/kg-k	610 J/kg-k

The sol-gel process is a wet chemical technique widely used in the fields of materials science and ceramic engineering. Such methods are primarily for the fabrication of materials starting from colloidal solution that acts as the precursor for an integrated network of either discrete particles or network polymers. Typical precursors are metal alkoxides and metal salts, which undergo various forms of hydrolysis and polycondensation reactions. Nano ceria and alumina powder was mixed with B20 through magnetic stirring process for 1 hour and allowed to cool down the temperature of oil mixture generated while stirring. Through hydrolysis and polymerization process nano ceria and alumina sols are distributed. After precipitation, the nano powders are uniformly distributed in the B20.

Fuel Properties:

The fuel properties of diesel, B20 and nano additive fuel blends are compared in table 1.2. Due to transesterification, the B20 properties are slightly improved. In B20, again the properties are much improved. However, when the Ceria and Alumina nanoparticles were mixed with B20, all the properties are closer to diesel. The fuel properties in table show all are within the range of ASTM standards of biodiesel. After transesterification process the properties of the oil are changed. The viscosity and density have decreased as the nano additive content in the B20 blends.

Table 2: Fuel properties of the fuel samples

Properties	Diesel	B20 Jatropha oil	B20 + 25ppm (CeO_2 + Al_2O_3)
Kinematic viscosity at 40°C (cSt)	3.155	5.2	5.18
Calorific value (MJ/kg)	43.3	42.8	43.5
Density (kg/m^3)	0.834	0.844	8.35
Flash point (°C)	50	60	58
Fire Point (°C)	54	66	63

3. Experimental Set Up and Procedure:

Figure 1: Photographic view of experimental engine setup

The engine experimental tests have been conducted in a single cylinder, four stroke, 3.7 kW (5HP), water cooled, direct injection CI engine coupled with eddy current dynamometer. The fuel samples were supplied to the engine from the diesel tank and biodiesel tank placed in the panel board. The burette was also placed in the same panel board. When the fuel cork is closed, the fuel to the engine starts to flow from the burette and not from the fuel tank. The fuel flow rates were obtained by noting the time taken for 50 cc of fuel consumption. The photographic view of experimental engine setup and instruments used for measuring the

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performance and emission is shown in the figure 1.1. The engine was started and allowed to warm up for about 10 minutes. The engine was tested under four discrete part load conditions of 0 kW, 0.925 kW, 1.85 kW, 2.775 kW and 3.7 kW respectively.

For all load conditions, engine speed was maintained at 1500 rpm. In the first part, the readings were taken for fuel consumption and emissions at each load for diesel and B20. Similarly, in the second part, the readings were taken for fuel consumption and emissions at each load for the fuel blend of B20 with 25 ppm of Ceria and Alumina respectively.

4. Results and Discussion:

Brake Thermal Efficiency (BTE):

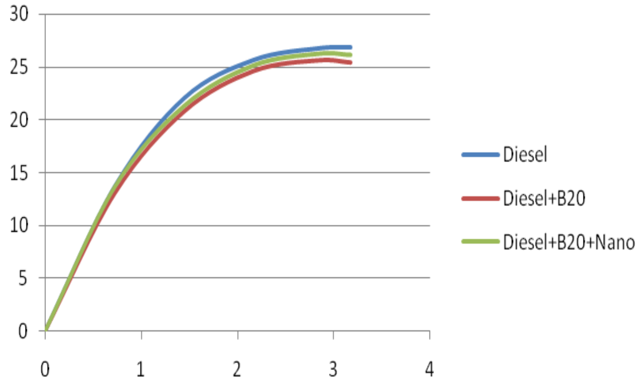

Figure 2: Graph showing Brake power (kW) Vs Brake thermal efficiency (%)

The brake thermal efficiency is a function of the engine parameter, which indicates how efficiently the fuel energy gets converted into mechanical output. The brake thermal efficiency increases with increase in loads for all tested fuels are shown in the figure 2. Brake thermal efficiency is slightly lower for B20 blends with ceria and alumina nanoparticles compared to diesel at all loads. The maximum brake thermal efficiency of B20 was found to be 25.4%. It is almost closer to diesel at full load condition. The brake thermal efficiency of B20 doped with ceria and alumina nanoparticles has increased by 2.75% compared to that of B20 and decreased by 2.97% compared to neat diesel. This may be due to the better spray characteristics and dissolved oxygen in B20 blends in the combustion chamber. This leads to the effective usage of air resulting in complete combustion. The decrease in brake thermal efficiency in biodiesel compared to diesel was that poor spray properties, higher viscosity and lower calorific value. Brake thermal efficiency for B20 with 25 ppm of ceria and alumina fuel blends are higher than the B20 due to high calorific value of nanofuels combined with better combustion characteristics of nanoparticles such as higher surface to volume ratio allows more amount of fuel to react with air to enhance the brake thermal efficiency. Other reason was found to be the nano blends giving rise to high calorific value. [1]

Unburned Hydrocarbon (HC):

The variations of HC emissions with engine load for neat diesel, B20 and B20 blended with cerium and aluminium oxide nanoparticles are shown in the figure 1.3. Hydrocarbon emissions of the blends are lower in partial load, but increases at higher load. This is due to the availability of relatively less oxygen for the reaction when more fuel is injected into the cylinder at higher load. [8] The hydrocarbon emission of diesel at maximum load is 110ppm, whereas B20 is 104 ppm. HC emission of B20 is closer to diesel, but in a decreased rate of about 0.54%. This is due to the fact that cetane number of biodiesel is higher than that of diesel. The effects of shorter delay period results in lower HC emission. In addition, the intrinsic oxygen contained by the biodiesel and increasing oxygen content resulting in better combustion were responsible for the reduction in HC emissions. [7] Unburned fuel is caused for producing HC emission. Hydrocarbon emissions for the nano additive fuel blends are lower than B20 by 1.15% and neat diesel by 3.84%. This is mainly due to the perfect mixing of fuel with air and an increase in oxidation properties due to its oxygen boosting catalytic nature. Another reason was nano additive blended fuel having higher surface to volume ratio. [3]

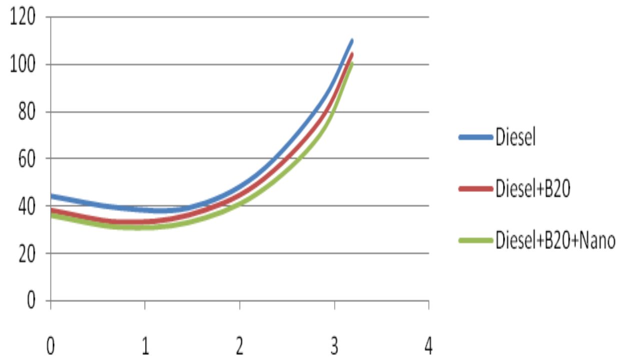

Figure 3: Graph showing Brake power (kW) Vs Hydrocarbon (ppm)

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Exhaust Gas Temperature:

EGT represents the temperature of the fuel mixture after combustion in the engine cylinder. It can be measured at the exhaust manifold. Due to its high sensitivity for dynamic phenomena and its accessibility for measurement, the EGT has been used towards the detection of combustion anomalies. Furthermore, in order to get more in depth information about the combustion process, the in-cylinder pressure values have also been monitored.

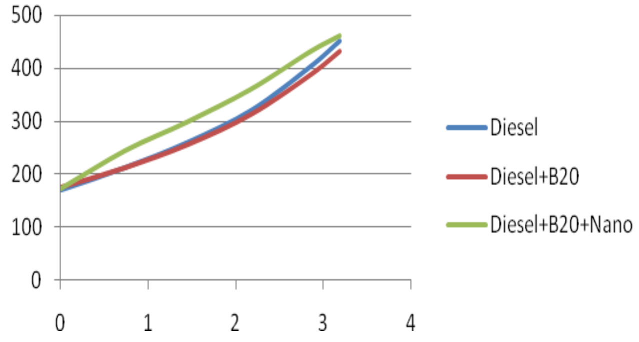

Figure 4: Graph showing Brake power (kW) Vs Exhaust gas temperature (^oC)

The variations of the EGT with respect to brake power are shown in the figure 1.4. It is observed that the EGT for the nanoparticle blended fuels was higher than that of the B20 and neat diesel. It is due to the rapid evaporation and in turn resulting in higher cylinder average temperature. This could be due to the improved combustion, better homogenization reactant mixture. [9] From the graph, it was found that the EGT at maximum load of diesel is 451°C, whereas for B20 it is 432°C and B20 doped with nanoparticles is 460°C. It is found that the exhaust gas temperature of B20 doped with nanoparticles was increased by 1.99% compared to neat diesel and increased by 6.48% compared to B20.

Oxides of Nitrogen (NO_x):

The variations of NO_x emissions with engine load for diesel, B20, with and without nano additives are shown in the figure 1.5. It is observed that the NO_x emissions increase with an increase in loads for B20. This is due to the increase in combustion temperature whereas there is an increase in the amount of fuel burned with load. NO_x emission in B20 is higher than the neat diesel because they have high viscosity which gives poor atomization and combustion leads to higher combustion temperature. [10] At high load, the NO_x emission is increased because faster premixed combustion result for an increase in cylinder temperature and so NO_x discharge increases. The minimum NO_x emission is detected for neat diesel at no load and half load conditions. The NO_x discharge is minor for diesel when matched to all other blended fuels. The figure 1.5 displays the deviation of nitrogen oxide discharge for diesel blended with nanoparticles compared with neat diesel. NO_x formation is fully dependent on the combustion temperature. [11] In general, the NO_x emission varies linearly with its increasing load. As the load increases, the overall fuel-air ratio increases and then the temperature increases in combustion chamber. The NO_x emissions for the nano additives fuel blends are higher than B20 because nano additives being an oxygen boosting catalyst supports complete combustion of the fuel and increases the combustion chamber temperature, which in turn leads to an increase in NO_x. As Cerium oxide is high oxygen donating catalyst and Aluminium oxide showing its higher thermal behavior, B20 doped with nanoparticles shows a moderate NO_x emission. NO_x emission is increased by 1.21% when compared with neat diesel and decreased by 3.41% when compared with B20.

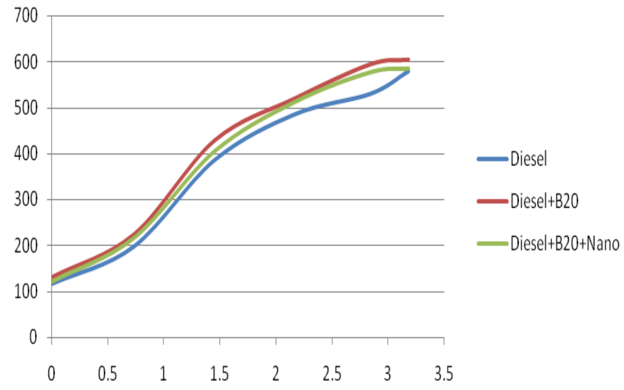

Figure 5: Graph showing Brake power (kW) Vs Oxides of nitrogen (ppm)

Carbon Monoxide (CO):

The variations of CO emissions with different engine load for diesel, B20 doped with and without nano additives are shown in the figure 1.6. CO is produced by the partial oxidation of carbon containing compounds. Generally in combustion process carbon dioxide is formed after combustion. But when there is not enough oxygen for combustion process, carbon monoxide forms, that is incomplete combustion. [12] From the graph, the minimum and maximum CO produced was 0.09 and

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0.92% at partial load to full load condition. The CO emission of diesel at maximum load is 0.92% whereas B20 is 0.79%. The emission of B20 is decreased greatly by 6.45% compared to neat diesel due to high viscosity, slighter increase in specific gravity.

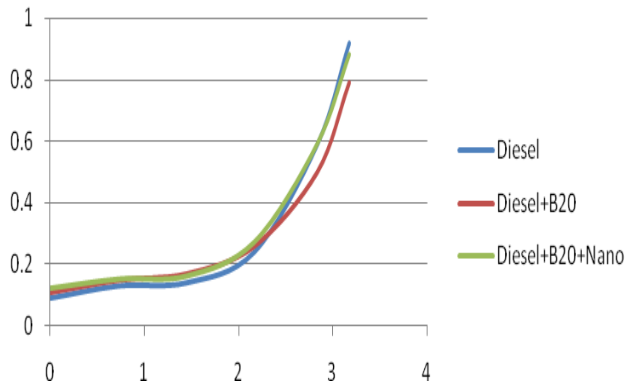

Figure 6: Graph showing Brake power (kW) Vs Carbon monoxide (%)

When B20 doped with nano-blends is compared with neat diesel and it showed a decrease in CO emission of 4.11%. This is because of the characteristic feature of nano fuel blended with B20. Cerium oxide is a good oxygen donating catalyst and has higher surface to volume ratio which allows more amount of air to react with air and with the lean mixture, CO emissions would be lower. [6]

Carbon dioxide (CO_2):

The variations of CO_2 emissions with engine load for diesel, B20 doped with and without nano additive of B20 are shown in the figure 1.7. CO_2 emission increases with an increase in brake power. The emission of CO_2 is more or less similar to B20 doped with nano particles when compared with diesel and B20. It is also noted that CO_2 increases steadily for all neat diesel, B20 doped with and without the nanoparticles. It is also observed from the experimentation values that carbon-dioxide emissions for diesel is higher when compared with B20 by 3.81% and B20 doped with nanoparticles by 3.94%. This is due to its reduced release of brake thermal efficiency. The CO_2 emission for B20 is very close compared to B20 doped with nanoparticles by only 0.13% due to its low carbon content in biodiesel and has a lower elemental carbon to hydrogen ratio than diesel fuel. [13] Also the CO_2 emissions in B20 jatropha nanofuels blends are slightly greater due to the higher oxygen content binding in oxide nanoparticles. Due to the oxygen boosting catalytic nature of cerium oxide nanoparticles, it promotes better combustion leading to the higher CO_2 emission that without nano additive blends and diesel. [14]

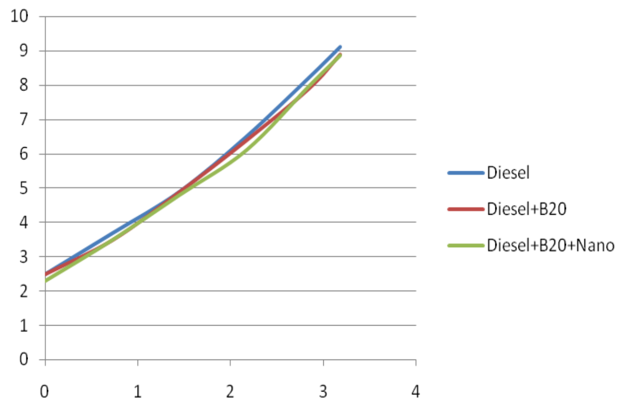

Figure 7: Graph showing Brake power (kW) Vs Carbon dioxide (%)

Smoke:

The variations of smoke emissions with engine load for diesel, B20 with and without nano additives are shown in the figure 1.8. For all, smoke increases simultaneously with an increase in load. From the graph, neat diesel emits smoke about 65 HSU whereas B20 emits about 52 HSU and the nano additive blended B20 emits 61.5 HSU which is higher than B20 but lesser than the neat diesel. From the graph, smoke emissions are less for B20 when compared with neat diesel by 2.15% and increased by 1.54% for B20 doped blended with nano additives. The low viscosity of the B20 as well as oxygen present in the molecules decreases the rate of combustion by increasing the smoke levels in B20. This happens also due to combustion duration and increased ignition delay of gas – phase emissions compared with the lower blends. [15] The smoke emission is mainly due to higher viscosity and lower volatility which results in poor mixture formation. The smoke emissions of B20 doped with nanoparticles are lower than B20. Due to the shortened ignition delay, higher surface to volume ratio results in perfect mixture formation, quick evaporation rate and improved ignition characteristics of nano additives. Because NO_x and smoke are trade off. [16]

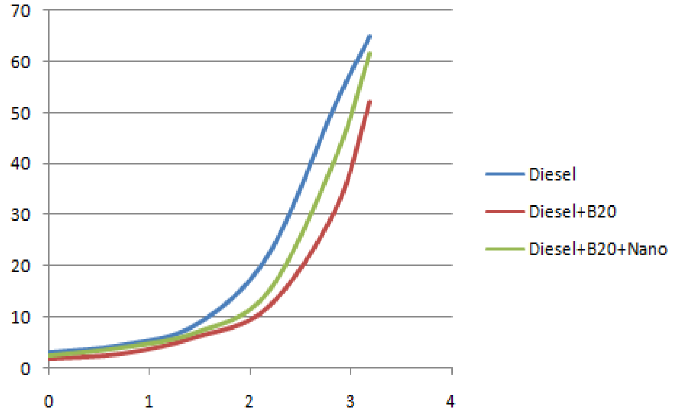

Figure 8: Graph showing Brake power (kW) Vs Smoke (HSU)

5. Conclusion:

The performance and emission characteristics of B20 doped with cerium and aluminium oxide nanoparticles were investigated in a single-cylinder, constant speed, CI-DI engine. Based on the experimental results, following conclusions were made.

- B20 doped with nanoparticles showed low calorific value than neat diesel that helps in reducing unwanted combustion.
- Flash and fire point of B20 doped with diesel is increased ensuring the safety of the usage of fuel.
- The nanoparticle blended fuel blends leads to a good improvement in the brake thermal efficiency up to 2.75% and lowering the fuel consumption.
- This study gave a settlement for Carbon monoxide emission also. The CO emission is highly reduced by 4.11% when compared with neat diesel enhancing combustion.
- According to the experimental investigation, the unburned hydrocarbon emission is highly reduced up to 3.84% when compared to neat diesel.
- Carbon dioxide emission is highly reduced by 3.94% due to low carbon content and higher oxygen binding capacity.
- This experimentation also concluded that the NOx value has reduced highly by 1.21% when compared with neat diesel.
- Smoke emission has slightly increased in this experimental investigation. It is increased by 1.54% when compared with neat diesel.

Thus Biodiesel from Jatropha oil (B20) blended with nano additive of 25 ppm of Cerium oxide and Aluminium oxide is well suited as an alternative fuel for diesel engine and also acts eco-friendly.

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