Experimental Study on Nanofluid Fuel and Its Effects on the Performance of CI Engine

S.P.Venkatesan[1*], P.N.Kadiresh[2]
[1]Department of Mechanical Engineering, Sathyabama University, Chennai, India
[2]Department of Aeronautical Engineering, B.S.AbdurRahman University, Chennai, India
[*]Corresponding Author: E-Mail: spvsathyabama@gmail.com

ABSTRACT

This experimental investigation focuses on the significance and influence of cerium oxide in its nanoparticle profile on the physicochemical properties and the performance of diesel blends when compared with pure diesel. Cerium oxide in its nanoparticle form, exhibits an unprecedented catalytic activity due to its oxygen buffering capability. Cerium oxide, when allowed to be used as an additive in a diesel engine, is known to exhibit depreciation of oxides of nitrogen and hydrocarbon emissions respectively. Dodecenyl Succinic Anhydride (DDSA) is the surfactant being used so that the cerium oxide-diesel blends remain stable. The cerium oxide is subjected to different procedures such as EDS, XRD, and SEM test for their characterization. The cerium oxide-diesel blends were successfully obtained with the means of an ultrasonic bath sonicator, in a two staged procedure. The influence of cerium oxide on the physicochemical properties of pure diesel has also been explored through comprehensive studies by means of ASTM testing techniques. Load test was conducted on the CI engine so as to examine the aftermath from the effect of cerium oxide on the efficiency and emissions from the CI engine. Comparison of physicochemical properties with and without additives are perceived and disclosed.

KEY WORDS: Nanofluids, cerium oxide, Dodecenyl Succinic Anhydride, Diesel engine, performance, emissions.

1. INTRODUCTION

CI engines are naturally blessed with a high efficiency which makes them popular than petrol engines in the ever competing automobile industry. But, the popularity and the increase in the diesel run vehicles has amassed a large increase in the emissions such as hydrocarbons, particulates, oxides of nitrogen, and derivatives of sulphur oxides. The emission of these harmful gases has directly influenced the chances of acid rain and photochemical contagion going higher. Thus, the amassed usage of diesel engines are considered to be a rising threat and stringent emission legislation are to be undertaken to decrease the emissions. The reformulation and provision of a better fuel than diesel is a major hurdle to be addressed upon, since the fossil fuels are gradually slipping to complete exhaustion day by day. Efforts are made to reformulate a better fuel without affecting their physicochemical properties such as Density, Viscosity, Flash Point, Fire Point, Calorific Value, and Cetane Number (Gu and Soucek, 2007). Normally metal oxides of copper, cerium, cobalt, iron are known to be chosen as fuel additives (Arul Mozhi Selvan, 2009; Sajith, 2010; Vincentlottko, 2007). Among them, Cerium Oxide is the element which is found in abundance in the extremely rare earth metal family with good cross over efficiency and high thermal stability. Cerium oxide is found to undergo redox cycling between their oxidation states (tri and tetra valent). Since, high surface-to-volume ratio results in the improvement of the efficiency and reduction in emissions, cerium oxide is known to exhibit high catalytic activity (Satge de Caro, 2001).

2. EXPERIMENTAL TEST PROCEDURE

The experimental procedure can be divided into two stages. First, the present experimental study mainly focuses on the reformulation of a better fuel using cerium oxide in its nanosized form, without changing the physical (or) chemical properties of the fuel such as Density, Viscosity, Cetane Number, Flash Point, Fire Point, and Calorific Value. The experiment involves the rendering of diesel blends by varying the dosage levels of Cerium oxide nanoparticles (750mg & 1000mg) and the DDSA (2.5 & 5 Vol %) respectively. The samples which are mixed are later transferred to the ultrasonic bath sonicator which has a digital timer in the middle of the device. The timer is set as default to 15 minutes of mixing. The stable suspension sample creation was executed with caution and attention since the weighing of the nanoparticles posed a great challenge. The accurate weighing of the cerium oxide nanoparticles is measured with the aid of a Unibloc Analytic Balance. In total, five samples are created, likely 1litre Diesel+750mg Cerium, 1litre Diesel+1000mg Cerium, 1litre Diesel+1000mg Cerium+2.5% DDSA, 1litre Diesel +1000mg Cerium+5%DDSA respectively and one pure diesel sample. These samples are later transferred to new containers in such a way that each sample is contained in two containers (500ml each). One set of samples is sent to perform the physical properties analysis such as Density, Viscosity, Flash Point, Fire Point, Cetane Number, and Calorific Value. Another set of samples are input in a diesel engine so as to determine the thermal efficiency and the hydrocarbon emissions. Secondly, the cerium oxide-diesel-DDSA blends are subjected to load analysis on CI engine so as to find the performance and emissions of the engine. From the Engine Run Test, The Brake Thermal Efficiency, Specific Fuel Consumption and Total Fuel Consumption were calculated with the help of formulas and emissions such as hydrocarbon and nitrogen oxide emissions were measured using a Standard Emission Analyzer (DI GAS

444 AVL) and AVL smoke meter. The block diagram of the experimental setup and specification of engine are shown in Figure 1 and Table1 respectively. The graphs were plotted accordingly against BP to find the IC engine performance and exhaust emissions. The tests were compared and contrasted with pure diesel (D) and nanoparticle induced diesel fuel. The standard testing procedures are conducted on the Cerium oxide nanoparticle form so that the determination of the nanoparticles which is Cerium Oxide can be confirmed from the tests (Muruganantham Chelliah, 2012). The EDS and the XRD test are done to determine and confirm on the major elements present in the Cerium oxide nanoparticles as shown in Figures 2 and 3. The EDS and XRD analysis on cerium oxide confirmed that Oxygen and Cerium are the major elements present in the nanoparticle composition with weight percentage 41.38 and 58.62 respectively. The SEM test is conducted on the cerium oxide nanoparticles so as to determine the size of the nanoparticles which will come around 40 to 50nm as depicted in the Figure 4.

3. RESULT AND DISCUSSION

Flash and fire point: Flash point is the temperature at which a flash is initially produced on the introduction of a spark on the surface of a heated fuel and is also an indication of how volatile a fuel can be. The temperature, at which the flame becomes self-sustained so as to continue burning the liquid, is called fire point. Higher the volatility of a fuel, lower will be the flash point and vice versa also is applicable. Flash point was tested for the nanoparticle added diesel up to a dosage level of 750mg to 1000mg, which indicated a decrease in the volatility of the fuel with the addition of cerium oxide. The flash and fire point were found to be increasing with the addition of the dosage levels of the cerium oxide nanoparticles to the diesel blends.

Kinematic viscosity: Kinematic viscosity is the ratio of absolute (or dynamic) viscosity to density a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with the fluid mass density. Now, with the addition of cerium oxide nanoparticles at different dosing levels have seen an increase in the kinematic viscosity due to the fact that the addition of cerium oxide has increased the resistance which resides in between the fluid layers hence increasing their kinematic viscosity. The DDSA was added so as to obtain a stable suspension but the addition of DDSA has incurred in the decrease of the kinematic viscosity since the increase in the stability of the suspension gives way to the decrease in their viscosity. Thus, the kinematic viscosity is seen to increase with the addition of cerium oxide nanoparticles but decreases with the addition of a surfactant (DDSA).

Brake thermal efficiency: The load being used in the engine run has been taken as a number of constant values so that the uniform load can be maintained in all the experimental observations leading to a more accurate result. The brake thermal efficiency of D+1000cerium+50DDSA blend was better than that of other blends as seen from Figure 5. An increase of 7% was observed at full load. The cerium oxide being known to have an excellent catalytic activity due to its high oxygen buffering allows a longer and more complete combustion when compared with the pure diesel fuel. It also influences the storage and release of oxygen depending upon their partial pressures. The effect of the surfactant (DDSA) on performance of diesel engine has also been instigated. As the DDSA is added to the blends, an increase in the efficiency has been observed since the DDSA decreases the viscosity drastically resulting in the better atomisation of the fuel particles at its atomic level which leads to an increase in their efficiency.

Specific fuel consumption: Specific Fuel Consumption is defined as the fuel flow rate per unit power output. It is a measure of the efficiency of the engine in using the fuel supplied to produce work. From the Figure 6, the specific fuel consumption was found to have been decreased up to 5.6% with cerium blends when compared with pure diesel. The SFC is found to be decreasing due to the addition of cerium oxide, which promotes combustion of the diesel fuel (Allen C, 2011). This in turn, requires the engine speed to run at a constant rate, for which less quantity of fuel is to be consumed. Hence, we are observing a decrease in the specific fuel consumption with the addition of cerium oxide nanoparticles. It is desirable to have a lower value of SFC which means that the engine will use less fuel to produce the same amount of work.

Hydrocarbon emissions: From the Figure 7, the hydrocarbon emissions were seen to have decreased by 46.1% for D+1000cerium+50DDSA blend at the maximum load. As the experimental analysis was conducted, the hydrocarbon emissions were found to have been decreasing with the addition of cerium oxide nanoparticles from 750mg to 1000mg to the diesel blends. When cerium oxide nanoparticles get added to the diesel blends, they have the ability to transform themselves from their stoichiometric +4 valence state to their +3 valence state, thus making sure that the released oxygen from their process is utilised for the oxidation of the soot and the hydrocarbon (Dutta P, 2006), so that their conversion to Ce_2O_3 is made possible. The addition of DDSA only further leads to a reduction in the hydrocarbon emissions.

Oxides of nitrogen emissions: The variation of NO_X emission for D+cerium+DDSA blends and standard diesel for different load is shown in Figure 8. The NO_x emissions were found to have been decreased by 38.5% for 1000mg cerium blend at maximum rated load. Also, a reduction has been observed when the dosing levels of the nanoparticles were increased gradually. The reason being that the cerous oxide (Ce_2O_3) formed from the oxidation of the hydrocarbon gets reoxidised due to the reduction process of the nitrogen oxide. The following reaction is noted below as follows.

$$Ce_2O_3 + NO \rightarrow 2CeO_2 + 1/2\ N_2$$

NO_x emissions were found to have been decreased with the addition of cerium oxide nanoparticle and further reduction up to 40% with the addition of extra 25ml volume fraction of DDSA. With the addition of DDSA, the viscosity of the fuel decreases and better dispersion of cerium oxide nanoparticles which acts as a nanofluid fuel is observed and noted duly, leading to further reduction in the emissions.

CO and SMOKE emissions: The CO and Smoke emissions at various load are shown in Figures 9 and 10. The CO and Smoke emissions were found to have been decreased by 38.5% and 26.4% respectively as the addition of cerium oxide nanoparticles were incorporated. Cerium oxide also exhibits its ability to act as an oxidation catalyst which in turn helps to lower the carbon combustion activation temperature and thus enhancing hydrocarbon oxidation, promoting complete combustion (Stanmore, 1999). Cerium oxide has been long being used as a catalytic converter for the minimisation of CO emissions in the exhaust gases from vehicles. There are two processes taking into effects which are listed below as follows:

When there is a shortage of oxygen, cerium (IV) oxide is reduced by carbon monoxide to cerium (III) oxide:

$$2\ CeO_2 + CO \rightarrow Ce_2O_3 + CO_2$$

When there is an oxygen surplus, the process is reversed and cerium (III) oxide is oxidized to cerium (IV) oxide:

$$2\ Ce_2O_3 + O_2 \rightarrow 4\ CeO_2$$

Table.1. Specification of diesel engine

Type	Single cylinder, direct injection, four stroke
Bore x stroke	87.5 mm x110 mm
Displacement volume	661.45 cc
Compression Ratio	Variable
Speed	1500r.p.m (constant)
Rated Power	3.5 kW
Cooling	Water cooled
Loading System	Eddy current dynamometer

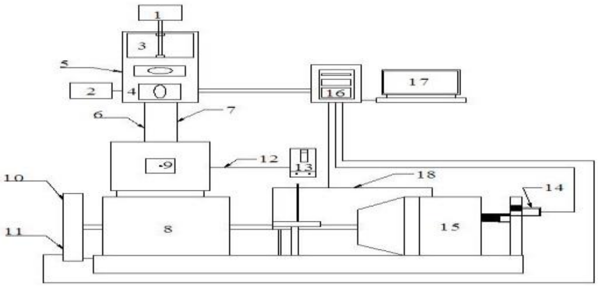

Fig.1. Experimental set-up

1. Fuel tank, 2. Air surge tank, 3. Sensor for fuel flow, 4. Sensor for air flow, 5. Control panel, 6. Air supply to engine, 7. Fuel supply to engine, 8. Variable compression ratio engine, 9. Cylinder pressure sensor, 10. Rotary encoder, 11. Engine speed sensor, 12. Engine exhaust gas outlet, 13. Exhaust gas analyser, 14. Load cell, 15. Loading device (eddy current), 16. Data collection card, 17. Computer, 18. Gas calorimeter.

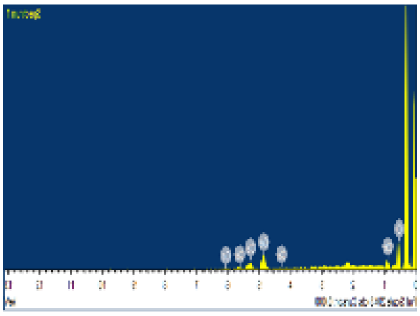

Fig.2. EDS spectrum of zinc oxide nanoparticles

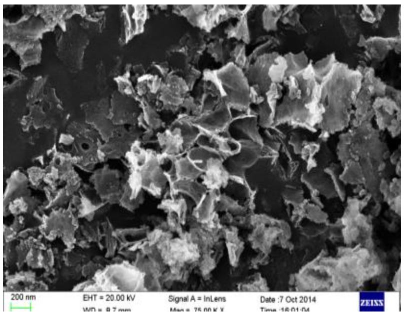

Fig.3. SEM images of zinc oxide nanoparticles

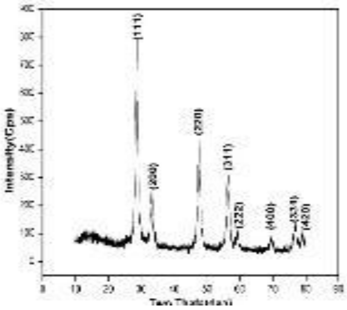

Fig.4. X-Ray diffraction pattern of zinc oxide nanoparticles

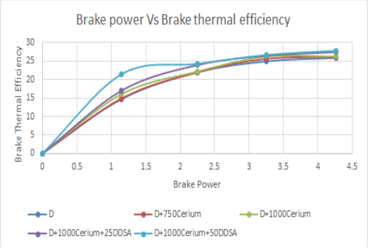

Fig.5. Variation of brake thermal efficiency with brake power

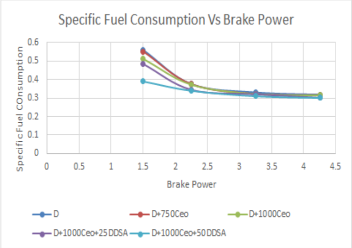

Fig.6. Variation of brake specific fuel consumption with brake power

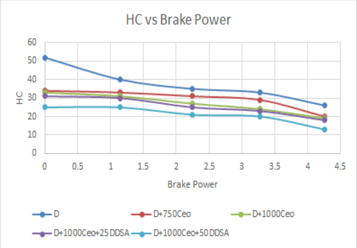

Fig.7. Variation of hydrocarbon with brake power

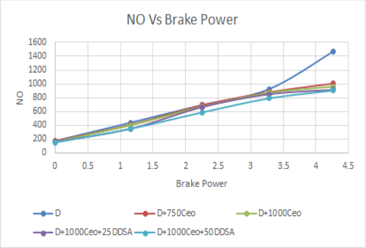

Fig.8. Variation of oxides of nitrogen with brake power

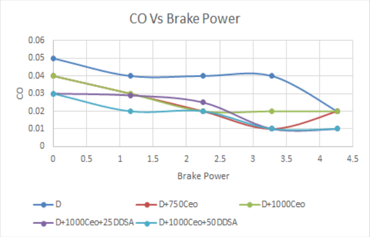

Fig.9. Variation of carbon monoxide with brake power

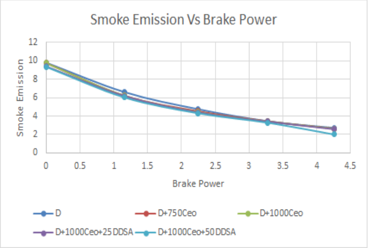

Fig.10. Variation of smoke with brake power

4. CONCLUSIONS

Load tests were conducted on diesel engine using cerium oxide mixed diesel blends and from the experimental results, the arrived conclusions are listed below

a) Flash point, fire point and kinematic viscosity values are marginally increased for cerium oxide mixed blends compared to pure diesel but addition of 5% (Vol) of DDSA to cerium oxide mixed blends helps to bring the values of these properties to almost equal to diesel.

b) As cerium oxide present in the diesel initiate more oxidation of hydrocarbons, the complete combustion of hydrocarbon occurred in the combustion chamber so that the thermal efficiency is increased to 7% and specific fuel consumption is decreased to 5.6% for D+1000cerium+50DDSA blend compared with pure diesel at the full load operated condition.

c) As the cerium oxide has the ability to oxidise hydrocarbons as well as reduce oxides of nitrogen simultaneously, the emissions of HC, CO, smoke and NO_X are reduced by 46.1%, 38.5%, 26% and 40% respectively at full load for D+1000cerium+50DDSA blend.

d) Also it is observed from the experimental results that the improvement in performance and reduction in emissions are proportional to the dosing level of cerium oxide present in the diesel.

REFERENCES

Allen C, Mittal G, Sung C, Toulson E, and Lee T, An aerosol rapid compression machine for studying energetic-nanoparticle-enhanced combustion of liquid fuels, Proceedings of the Combustion Institute, 33, 2011, 3367-3374.

Arul Mozhi Selvan V, Anand R.B, and Udaykumar M, Effects of cerium oxide addition in diesel & biodiesel on the emission characteristics of a C I Engine, ARPN Journal of Engineering and Applied Science, 4, 2009, 1-6.

Dutta P, Pal S, Seehra M S, Shi Y, Eyring E M, and Ernst R.D, Concentration of Ce^{3+} and oxygen vacancies in cerium oxide nanoparticles, Chemistry of Materials, 18, 2006, 5144-5146.

Gu H, and Soucek M D, Preparation and characterization of monodisperse cerium oxide nanoparticles in hydrocarbon solvents, Chemistry of Materials, 19, 2007, 1103-1110.

Muruganantham Chelliah, Synthesis and characterization of cerium oxide nanoparticles by hydroxide mediated approach, Journal of Applied Science, 2012, 1737.

Sajith V, Sobhan C B, and Peterson G P, Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel, Advances in Mechanical Engineering, 2010.

Satge de Caro P, Mouloungui Z, Vaitilingom G, and Berge J C, Interest of combining an additive with diesel-ethanol blends for use in diesel engines, Fuel, 80, 2001, 565-574.

Stanmore B, B J –F and Gilot P, The ignition and combustion of cerium doped diesel soot, SAE Technical Paper, 1999.

Vincentlottko, The effect of titanium oxide in diesel oil mixture composition and particulate matter emission level in diesel engine, Fuel, 86, 2007, 1365-1371.