International Journal of Ambient Energy

ISSN: 0143-0750 (Print) 2162-8246 (Online) Journal homepage: http://www.tandfonline.com/loi/taen20

Investigation on the Effect of Thermal Barrier Coating at different Dosing Levels of Additives of cerium oxide Nanoparticle Fuel on Diesel in CI Engine

V.S. Shaisundaram, M. Chandrasekaran, S. Mohan Raj & R. Muraliraja

Publisher: Taylor & Francis & Informa UK Limited, trading as Taylor & Francis Group
Journal: *International Journal of Ambient Energy*
DOI: 10.1080/01430750.2018.1451385

Investigation on the Effect of Thermal Barrier Coating at different Dosing Levels of Additives of cerium oxide Nanoparticle Fuel on Diesel in CI Engine

V.S. Shaisundaram[1], Dr.M. Chandrasekaran[2], S. Mohan Raj[3], Dr.R. Muraliraja[4]
[1]Department of Automobile Engineering, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai
[2]Department of Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai
[3]Department of Mechanical Engineering, Easwari Engineering College, Chennai
[4]Department of Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai
shaisundaram@gmail.com (Corresponding Author)

Abstract

In the recent times, the limitations on the exhaust emissions of the internal combustion engines are becoming increasingly rigorous due to environmental safety. Carbon monoxide, oxides of nitrogen, particulates and hydrocarbon are the prime noxious waste emitted by diesel engines. This experimental study involves the analysis of engine performance and emission characteristics of a single cylinder diesel engine with yttria and ceria stabilized zirconia coating on cylinder liner and piston head. Varied dosing levels were added to diesel in both uncoated and coated engines. The experiment resulted in noticeable changes in the selected thermal barrier coating and dosing of cerium oxide additive nanoparticle in diesel. A surge of 2.1% in the brake thermal efficiency and downturn of 3% brake specific fuel consumption as compared to standard diesel mode in the uncoated engine was discerned. Emission level of nitrogen oxide, carbon monoxide and hydrocarbon also underwent considerable decline.

Keywords – Thermal barrier coating, diesel engine, cerium oxide, Engine performance, Emission.

1. Introduction:

The adverse environmental conditions due to pollution are often associated with human activities that are aimed at achieving material sophistication. The rapid urbanization and industrialization have elevated the escalating demands for transportation, electric power etc. Moreover, the speedy augmentation of industry has led to increased competitions and eventual pressure over these to provide newer products at a faster rate. All of these have aggravated the pollutant levels in the atmosphere to an alarming rate. Amplified level of pollutantsthat are being emitted from many of such actions of men have caused tragic effects on plants, animals and human beings. One of the most critical issues amidst such environmental issues is air pollution. Air pollution can in turn lead to depletion of the ozone layer, global warming and acid rain. The pollutants of air, like black carbon, contribute to both global warming and regional climatic changes. Emissions from automobiles like carbon monoxide, sulphur oxides and nitrogen oxides (NOx) are also some significant factors that causes degradation of our environment.

Presently, inner combustion engines are widely attacked because of the adverse effect it could cause to the atmosphere. Normally, a diesel engine tenders to better fuel economy than the petrol engine(Ramalingam, Rajendran, and Ganesan 2016). It is predicted that the world Motor Vehicle population shall raise to 1300 million by the year 2030, further specifically, close to 350 million in countries of Asia. By and large, those vehicles that employ hydrocarbon fuels lead to environmental pollution as they emit gases from diesel engines which are considered to be one of the prime pollutants (Pundir 2007). The chemical energy of the fuel is transformed to power which carries out mechanical work in automobiles. In the same process, pollutant gases are generated and released along with the exhaust gases from the engine. The alarming increase in these pollutant levels has attracted constant attention from many researchers who experiment on internal combustion engines by using higher technology to boost the performance of the engine with considerably reduced emission levels (Abedin et al. 2013; Abedin et al. 2014). The prime pollutants liberated by CI engines areoxides of nitrogen,unburned hydrocarbon, particulate and smoke. These can be removed by means of in-cylinder treatment, nevertheless, studies in literature have reflected that very few experiments have been carried out in this regard. Further, it was also found that catalytic pre-reaction amplifies the flame velocity and diminishes the minimum ignition energy requirements. Additionally, it was also stated that catalytic pre-chamber technology regulates the catalytic surface temperature as well as contact between the catalytic and gas phase reactants(Beyerlein and Wojcicki 1988; Shaisundaram et al. 2018). By and large, the metal oxides of copper, iron, cerium, and cobalt have been applied as fuel additives. The effect of composition of diesel particulate matterand cerium on the size distribution (Skillas et al. 2000).

Experimentally, it has been observed that cerium diesel fuel borne catalyst and bimetallic platinum reduces the engine emissions and improves the performance of the diesel particulate filter (Valentine, Peter-Hoblyn, and Acres 2000). On further experimentation (Jung, Kittelson, and Zachariah 2005), studies show that the addition of cerium to diesel fuel causes noteworthy changes in the number concentration of particles in the accumulation mode, kinetics of oxidation and light-off temperature. Although the oxidation rate increased considerably with the addition of cerium to the fuel, the dosing level did not have much noticeable influence(Jung, Kittelson, and Zachariah 2005; Stanmore et al. 1999). Sajith et al (Sajith, Sobhan, and Peterson 2010) evaluated the impact of adding cerium oxide to biodiesel with respect to engine performance and emissions. They inferred an increase in efficiency along with a downturn in NOx and HC emissions.

Presently, constant efforts of many researchers are consistently focussed on discovering an automobile engine with better performance. This is mainly done by applying thermal barrier coating (TBC) to increase the heat resistance inside the combustion chamber and offer a quantum leap in operating temperature of the internal combustion engine with durability. To withstand the thermal shock, the TBC must have a high coefficient of thermal expansion that matches well with the metal substrate (Patnaik et al. 2017). Multiple ceramic coatings such as TiO2, Al2O3, mullite, CaO/MgO– ZrO2, YSZ are engaged in engine application(Cao, Vassen, and Stoever 2004; MohamedMusthafa, Sivapirakasam, and Udayakumar 2011; Lima and Guilemany 2007). Partially stabilized zirconia (PSZ), mostly 6–9% yttria stabilized zirconia (i.e. YSZ) are the most commonly used TBC material. They are found to show good performance even on the applications of higher temperatures like that of diesel engines, gas turbines etc (Lima and Trevisan 1999; Bengtsson, Ericsson, and Wigren 1998; Hejwowski 2010). The investigation of Kamo et al. (Kamo et al. 1999) has shown that TBC engine with its piston and cylinder head coated with 0.1 mm thickness of YSZ and the cylinder liner coated with 0.5 mm width of YSZ improved the fuel efficiency by 6% at all loads and speeds. In order to observe the authority of the thermal barrier coating (TBC) on efficiency and emission qualities and the way it is contrasted from that of baseline engine characteristics, a piston crown was coated with Yttria Stabilized Zirconia (YSZ). YSZ, considering its desirable physical properties such as high coefficient of thermal expansion, low thermal conductivity, high Poisson’s ratio, and stable phase structure at higher temperature conditions was chosen as the ideal material for coating the piston crown owing(Sivakumar and Senthil Kumar 2014).

The uniqueness of the work in this discussion is that it attempts to assess the performance, combustion and emission related problems pertaining to diesel engine with yttria and cerium stabilized zirconia coating on cylinder liner and piston head especially on addition of cerium oxide as additives of different dosing levels of 35ppm, 45ppm and 55 ppm into the diesel fuel. The experimentation aims at representing the variation in effectiveness and emissions of the engine. The results concerned with the experimental work are evaluated, examined and presented in a systematic manner. In the initial phase, the engine was operated with diesel and cerium oxide nanoparticle in diesel with dosing levels of 35 ppm, 45ppm and 55ppm respectively. The experimentation was repeated in the second phase, that is, after modification of the engine with a thermal barrier coating, for the purpose of comparison.

2. EXPERIMENTAL PROCEDURE AND DETAILS

2.1 Description of the test engine

For the purpose of experimentation, a single cylinder, 4 strokes, water-cooled diesel engine (Tv1 model Kirloskar, India) of 5.2 kW power at 1500 rpm was put touse. It was connected to eddy current dynamometer for loading. This eddy current type dynamometer wasfixed to the engine output shaft. In order to measure air flow rate, an air box fitted with orifice meter and manometer with a percentage of uncertainty ±1 was used. Table 1a summarizes the detailed specifications of the engine. And, the schematic arrangement of the experimental setup has been shown in Fig. 1 and table 1b. The fuel consumption was calculated physically by a calibrated glass tube. Precisely, the calculation was carried out through the measurement of the time required for the consumption of 10 cc of fuel.

Engine Parameters:

Table 1a - Specification of the engine

Parameters	**Values**
Model	Kirloskar TV-1
General Details	Diesel Engine Test Setup, Vertical Cylinder, Water Cooled
Rated Power	5.2 KW @ 1500 rpm
Speed	1500 rpm
Number of Cylinder	Single
Number of Strokes	4
Compression Ratio	17.5 : 1
Bore Diameter	87.5 mm
Stroke Length	110 mm
Ignition	Compression Ignition

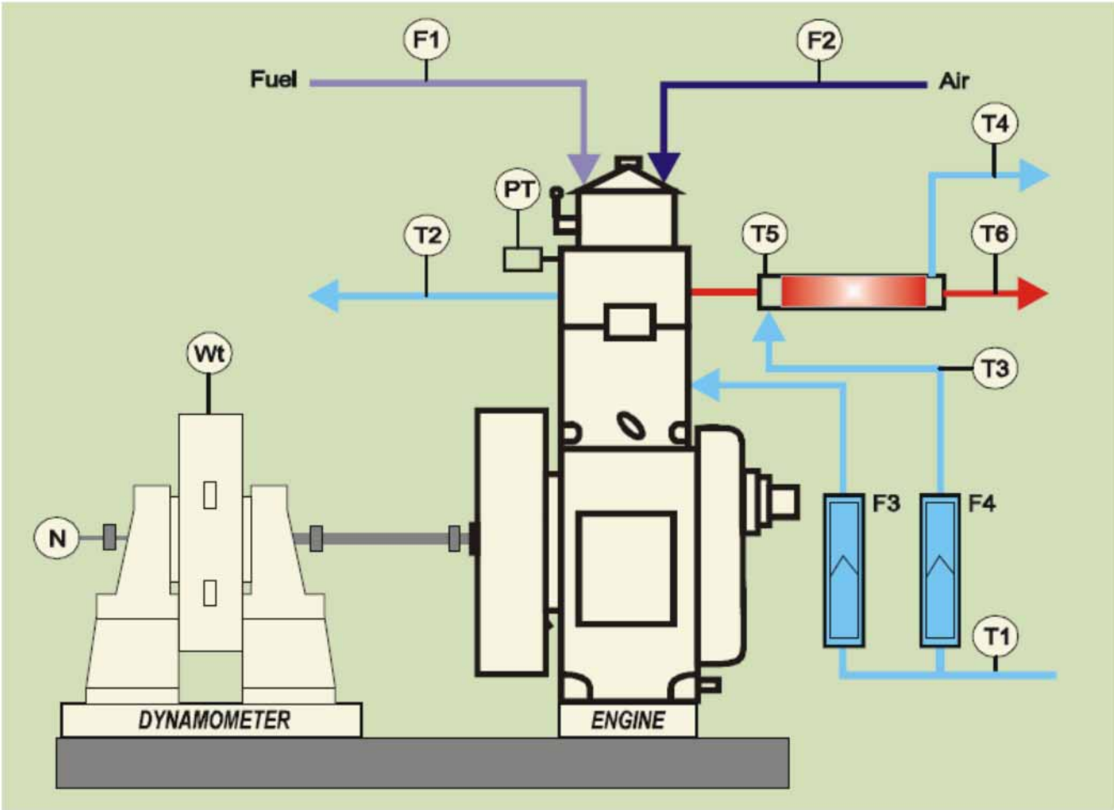

Fig 1 Experimental setup

Table 1b - Engine Components Description

Temperature	**Water Flow Litre per hour**
Engine cooling water Inlet **T1**	Fuel line **F1**
Engine cooling water Outlet **T2**	Air inlet **F2**
Calorimeter water Inlet **T3**	Engine cooling water 200 lph**F3**
Calorimeter water Outlet **T4**	Calorimeter water 100 lph**F4**
Calorimeter Exhaust gas In **T5**	Pressure transmitter **PT**
Calorimeter Exhaust gas Out **T6**	Crank angle Encoder **N**

The cylinder pressure and the crank angle were measured using piezoelectric pressure transducer (AVL INDIMICRA 602- T10602A) and magnetic pickup respectively. Further, for the measurement of engine speed, AVL 365C ANGLE ENCODER INDI ADVANCED was installed on the front-end of the crankshaft. An average value of the readings of about 50 cycles of the cylinder pressure for each steady-state was computed. Cylinder pressure and the rate of heat release were determined and carefully docketed in the computer. The values thus obtained were used in determining the corresponding graphs that aided the comparison of every single test blend with standard diesel fuel. AVL Digas 444, the five gas analyzer was used to measure the emission of CO, HC, NOx, CO_2, and O_2.Smoke and the exhaust gas temperature were exacted by an AVL437 smoke meter and k-type chromyl alumel thermocouple respectively.

The experimental tests were entirely performed under steady-state conditions with a stable speed of 1500 rpm. The tests were repeated thrice to determine the mean value. Further, the required emission parameters were determined and docketed only after the engine was provided with ample time to reach its steady state condition. The experimental data were verified and saved in a computerized data acquirement system for the purpose of analysis.

2.2. Thermal barrier coating synthesis by plasma spraying

There are many different types of thermal spraying technique like chemical deposition method, plasma arc method, physical vapour deposition method, and atmospheric plasma spray method. The current experimental study adopts plasma spray method. By grinding, a layer of 0.15 mm thickness and 0.30mm thickness was removed from the top surface of the piston and cylinder liner respectively. This was to maintain the same compression ratio in the coated piston and cylinder liner. The piston and engine cylinder liner were sandblasted with alumina grits for mechanical interlocking of sprayed powders and bulk. A composition of the coating powder is YSZ 94%; alumina 2% and Ceria 4%. Table 2 gives out the spray parameters employed for both coatings and Fig.2 shows a typical plasma spray coating technique.

Table 2 plasma spray coating parameter

Parameters	Values
Plasma Spray Gun	3 MB
Current I (Ampere)	500

Voltage V (Volts)	65-70
Maximum Power	40
Primary Gas flow -Ar (SCfh)	80
Secondary Gas flow -H_2(SCfh)	15
Spray Distance	2

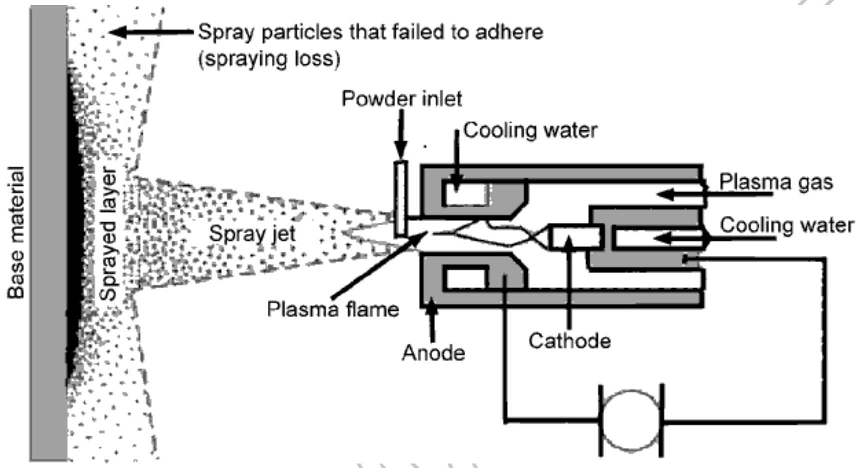

Fig. 2. Plasma spray Technique

2.3 Preparation of test fuel

This experimental study involves the usage ofdiesel as the prime fuel. The density and calorific value of the biodiesel were exacted using standard equipment. It was found to be 850 kg/m3 and 34.5MJ/Kg, respectively. Commercially available nanoparticles of Cerium oxide, size 10 to 20 nanometres and density of 7.13 g/mL was used as the fuel additive in this investigation. The cerium oxide nanoparticle samples in the base fuel were varied between dosing levels (by weight) 35ppm, 45ppm and 55ppm. The essential quantity of the nanoparticle sample for each dosing level was then computed using a precision electronic balance. Later it was mixed with the fuel using an ultrasonic shaker by unvarying application of agitation time of 30 minutes to effect a homogeneous suspension. In order to prevent sedimentation or any kind of settlement, the modified fuel was put to use as soon as it was prepared.

2.4 Determination of fuel properties

Ideal test methods were engaged for determining the viscosity; flash and fire points; and the pour and cloud points. The viscosity and the flashpoint were measured using the Redwood viscometer (British Standard Section 2000) and Cleveland open cup flash and fire point apparatus (ASTM 2007) respectively. Table 3 clearly presents the fuel properties of the fuel sample in concern.

Fuel Properties:

Table 3 Fuel Property

Properties	Normal Diesel	Diesel + 45 ppm CeO2
Density	849	845
Kinematic Viscosity @ 40 C cst (ASTM D445)	2.41	2.64
Calorific Value MJ/kg (ASTM D240)	42	41.694
Flash Point C	50	52
Fire Point C	58	60

2.5 Procedure for testing

Once the engine attained a steady state, readings were taken thrice, and the mean value was computed. The experimental data were promptly recorded. Cerium oxide, which was chosen as an additive for diesel, shows improved combustion process when intake air is added. This in turn results in the complete oxidation of HCs. Moreover, cerium oxide was miscible with diesel and was added to diesel with dosing level of 35ppm, 45ppm and 55ppm. It was then stirred for 30mins using an ultrasonic shaker to promote proper mixing. Later, the engine was operated with normal diesel at different dosing levels of cerium oxide added diesel and the readings were recorded. After completion of experimentation with baseline piston and cylinder liner, they were replaced with coated piston and cylinder liner. The same procedure was repeated and the performance, combustion and emission characteristic of both coated Engine (CE) and Non coated engine(NCE) for diesel added with the additive were compared with standard diesel. The coated engine was dismounted approximately after 100 h of engine operation for observation for any changes in coated piston crown and cylinder liner. The snapshots of coated piston crown and cylinder liner before engine operation are shown in Fig. 3.

The snapshots of coated piston crown and cylinder liner after engine operation are shown in Fig. 4 which further illustrates that the selected coating layer has minor cracks at the edges of the piston crown. Contrastively, in the remaining parts of both surfaces neither any cracks nor any abnormality was observed. This indicates the stability of the thermal barrier coating at all loading conditions of the engine operation.

Fig. 3. Coated Engine Piston and cylinder Liner

Fig. 4. Coated Engine Piston and Cylinder Liner after 100 h of engine Operation

3. RESULTS AND DISCUSSIONS

The examination of the effect of the coating of the cylinder liner and piston head was carried out on the basis of analysis of performance, combustion and emissions. Experiments were performed using diesel with cerium oxide additives of dosing levels 35ppm, 45ppm and 55ppm in a single cylinder, 4 strokes, water-cooled CI engine. The performance parameters like BSFC, BTE and emissions ofHC, CO_2, CO, NO_X, and smoke were measured and looked up for any discrepancies under varying engine loading conditions.

3.1 ENGINE PERFORMANCE

3.1.1 Brake specific fuel consumption

The difference in BSFC of TBC in both coated and uncoated enginewith engine load for diesel along with dosing levels of cerium oxides in diesel is shown in Fig. 5a. A comparative reduction of BSFC in diesel added with cerium oxide was observed to that of standard diesel (Kannan, Karvembu, and Anand 2011). Engine with TBC shows a further decrease in BSFC for diesel and diesel with cerium oxide additives. This is owing to the improved energy conversion rate that takes place during combustion as a consequence of increase in combustion temperature, eventually resulting in improved combustion. Eventually, this causes thelessening of the fuel consumption (Patnaik et al. 2017). At part load conditions, combined effect of coating and addition of different dosing of CeO2 to diesel has shown 3% lower BSFC than coated engine operated with diesel alone. This indicates an improvement in part load performance of the engine due to effect of CeO2. Moreover, an elevated temperature of the combustion chamber is noticed due to TBC. CeO2 with diesel increases the BSFC of coated engine by 1% and 2% with 45ppm and 55ppm respectively, at 75% engine load operation as compared to standard diesel operation in coated engine. Coated engine that operated with diesel alone has shown 3% reduction in BSFC than the baseline diesel mode operation at 75% engine load.

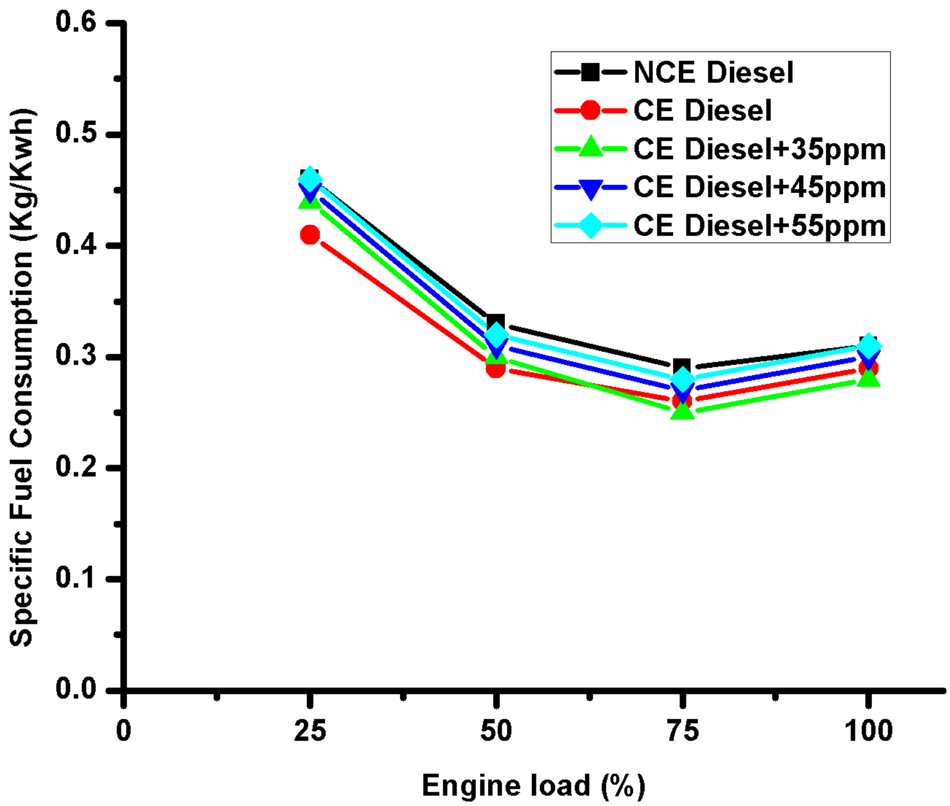

Fig. 5a Brake specific fuel consumption Vs Engine Load

3.1.2 Brake thermal Efficiency

The variation in BTE of TBC coated and uncoated engine with engine load has been shown in the Fig. 5b for all tested fuels. The BTE increases by addition of CeO2 in diesel. The cerium oxide nanoparticles present in the fuel stimulate longer and more complete combustion thanthat of the base fuel of the same cerium oxide that acts as an oxygen barrier, liberatingor holding back oxygen based on the partial pressure of oxygen. Hence, by the use of Cerium as additives, BTE was improved. It is significant that diesel with Cerium oxide in engine which is coated has higher thermal efficiency than that of diesel. This may be due to thermal resistance on the piston crown that hinders the loss of heat energy to the coolant and other media, leading to a more homogeneous combustion. Engine with TBC running with diesel alone shows 2.1% improvement in BTE than baseline diesel mode operation at 85% engine load.

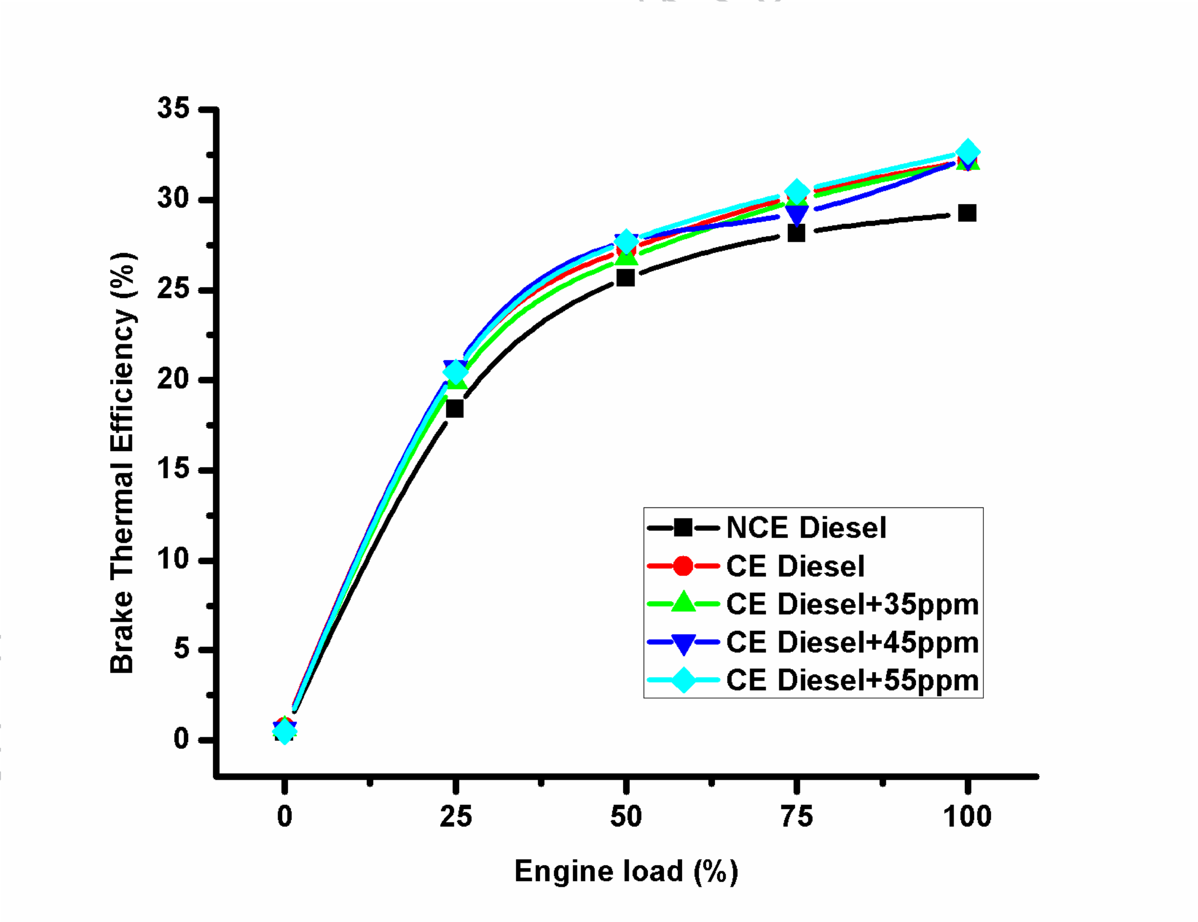

Fig. 5b Brake thermal efficiency Vs Engine Load

3.2 Emission Parameters

3.2.1 CO_2 emission

The variation of CO_2discharge with engine load is given in Fig. 6a. An upsurge in CO_2 emission is observed by dosing levels of CeO_2 in diesel than that of standard diesel. In this way,the combustion process is improved by the consumption of excess oxygen in the combustion chamber and thereby, enhancing the conversion of CO into CO_2 (Patnaik et al. 2017). Engine with TBC shows further increase in CO_2 emission. The elevated in-cylinder temperature and varying dosing levels of CeO_2 together improve the combustion process, leading to enhanced CO_2 emissions. The increase in CO_2 emission obtained for diesel with dosing of 35ppm, 45ppm and 55ppm of CeO_2 is about 5.7%, 7% and 8.9% respectively for coated engines at 75% of engine loading compared to standard diesel.

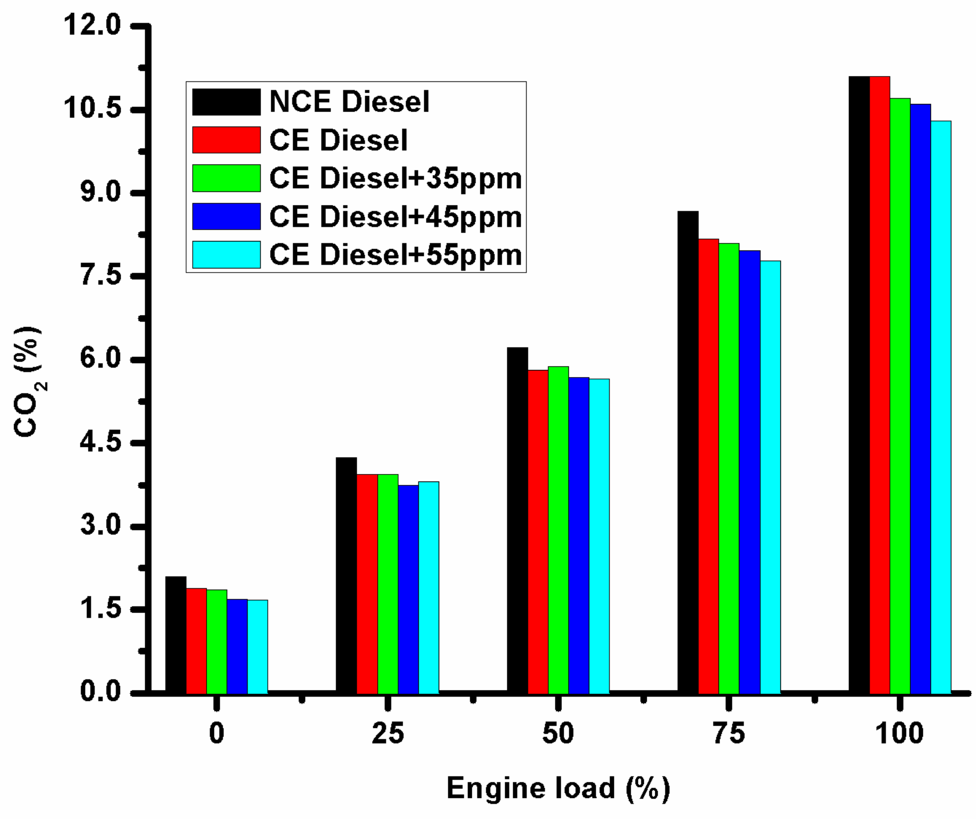

Fig. 6a CO2 Vs Engine Load

3.2.2 CO Emission

The CO emissions decrease with upsurge in the engine load as depicted in Fig. 6b. This is due to increase in combustion temperature with corresponding increase in the engine load which is responsible for reduced CO emissions. In the engine fuelled by diesel with CeO_2, the CO emission is reduced due to the improvement in the combustion processes induced by the actions of CeO_2. Clearly, it is due to the fact that CeO_2 enhances the conversion of CO into CO_2. Engine with TBC gives a further reduction in CO emission. As in diffusion combustion, the high temperature due to coating accelerates oxidation of CO into CO_2. This indicates an improved combustion in the diesel engine due to TBC (Hoseini et al. 2017). Due to dosing level 35ppm, 45ppm and 55ppm of CeO_2 into diesel, the CO emission is reduced by 0.8%,1.4% and 0.7% for coated engine respectively at 75% engine load operation as compared to standard diesel.

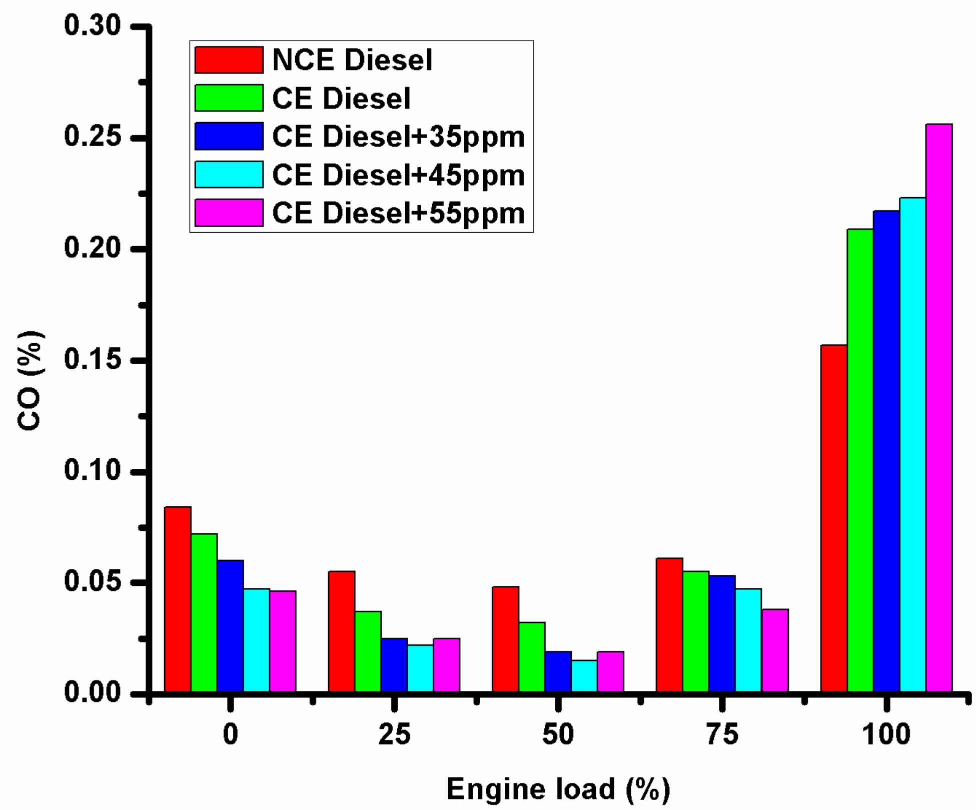

Fig. 6b CO Vs Engine Load

3.2.3 HC Emission

HC is generated when the combustion processes are not complete i.e. when unburnt or partially burnt fuel is present in the exhaust. The change in HC emission with engine load is given in Fig. 6c. When CeO_2 is added to diesel the HC emission is decreased by about 7% at 75% engine load as compared to the case when the engine is fuelled by diesel alone. This may be due to the effect of CeO_2 for augmenting the combustion efficiency. The emission of

HC in the coated engine is significantly reduced than uncoated engine. This could be attributed to increase in combustion temperature during afterburning phase because of decline in heat loss in coated engine. As a result, the improved combustion process leads to efficientuse of the intake air with an improved oxidation of the supplied fuel(Chan and Khor 2000). Diesel with 35ppm, 45ppm and 55ppm shows a reduction in HC emission by 9%, 8% and 6% for coated engine respectively contrasted to uncoated engine with standard diesel.

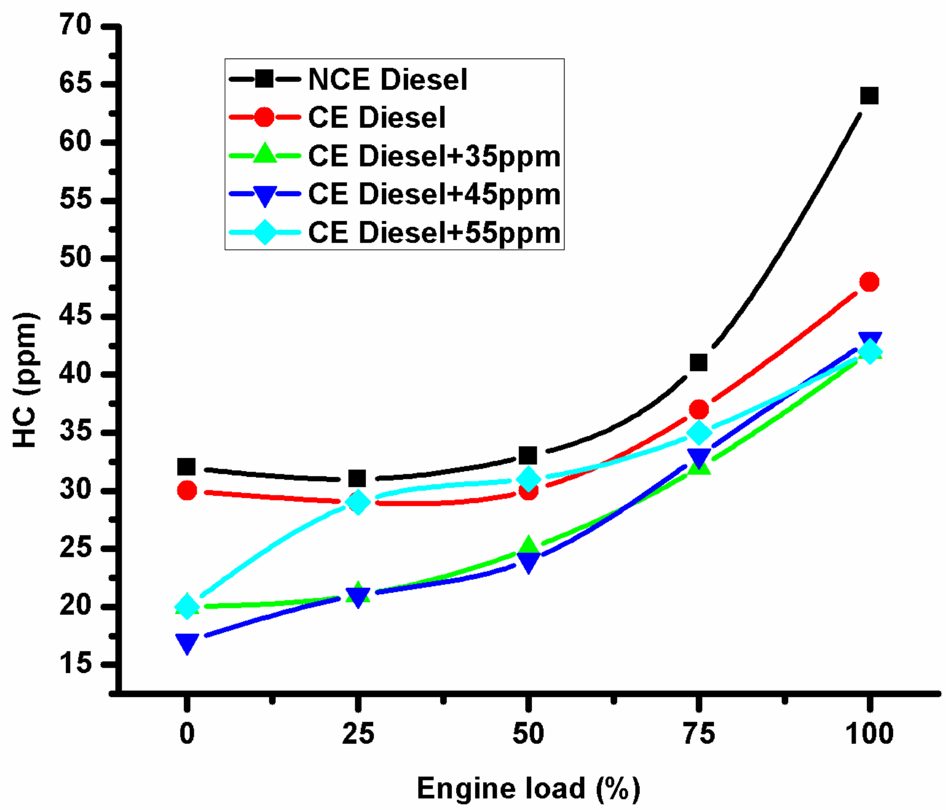

Fig. 6c HC Vs Engine Load

3.2.4NO$_X$ Emission

Fig. 6d exhibits that NO_X emissions increases with an increase in the loads of the engine.Combustion temperature and oxygen content are determined by the NO_X emission. On addition of CeO_2 into diesel, an increase in NO_X emission is observed, which is comparatively higher than in that of standard diesel. This can be due to the oxidation of nitrogen into its corresponding oxide, that is, nitric oxide by CeO2 during the process of combustion. The emission of NO_X in the uncoated engine is comparatively higher. This may be the effect of high combustion temperature that eventually leads to the early start of combustion that shifts the peak pressure and temperature to the proximity of TDC. As a result, most of the fuels burn in pre-mixed phase, which in turn is responsible for an increase in NO emission (Karikalan et al. 2017). Diesel with 35ppm, 45ppm and 55ppm show a decreased NO emission by 21%, 26% and 25.5% respectively for engine that is coated compared to that which is not, at 75% engine load operation with standard diesel.

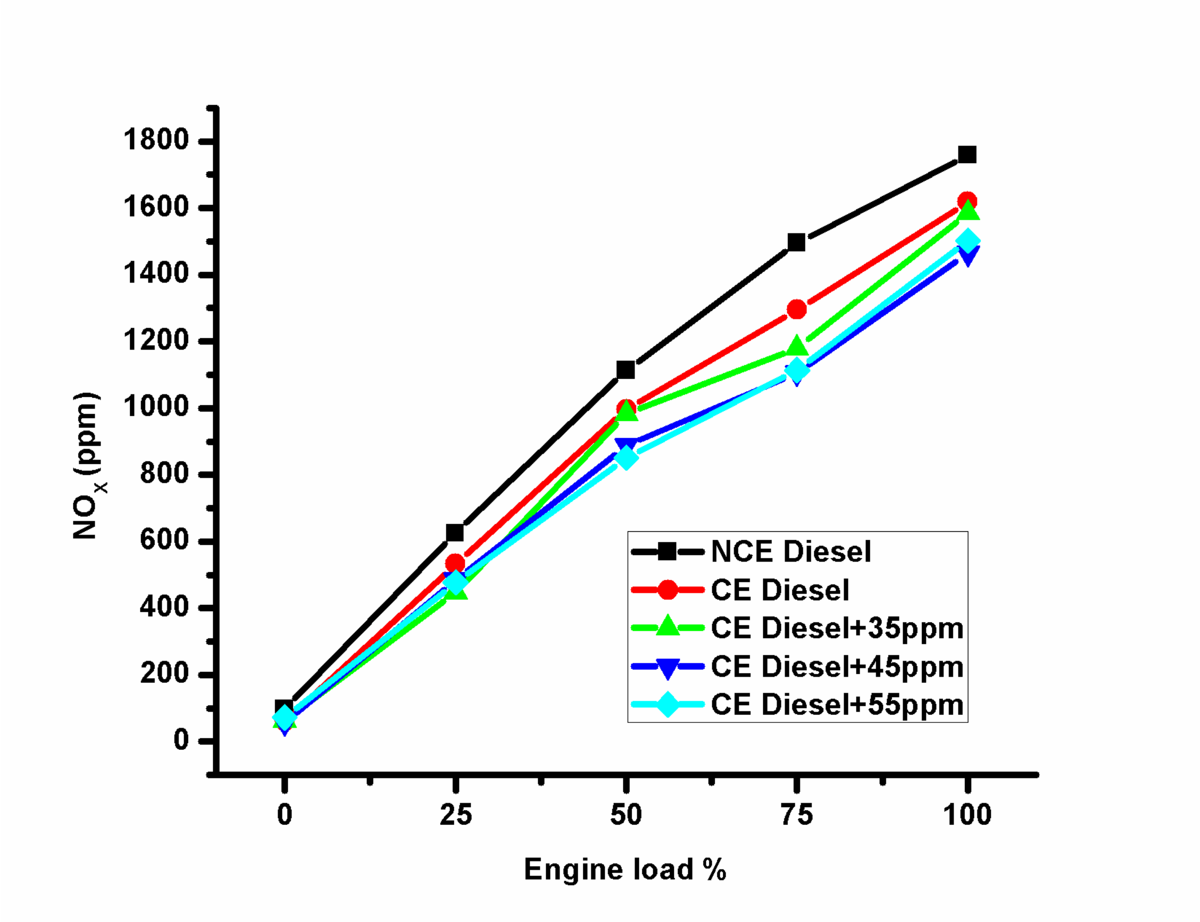

Fig. 6d NOx Vs Engine Load

4. CONCLUSION

The present investigation and the concerned experimental study that has been discussed above, validates the following conclusions,

- Engine with yittria and ceria stabilized zirconia coating with varying dosing levels of CeO_2 and diesel combination as a fuel mixture shows an increase in BTE by 2.7%and decrease in BSFC by 3% at 75% engine load operation. At part load conditions, coated engine has shown betterperformance characteristics with tested fuels.

- CO, HC, and NOx for both coated and uncoatedengine decreasesconsiderably on addition of dosing levels 35ppm, 45ppm and 55ppm of CeO_2 to diesel whenthe engine is operated by standard diesel.
- The effect of the parameters such as the preparation time, the nanoparticle size, along with the dosing level, plays a vital role on the performance of the fuels modified with cerium oxide nanoparticles in such experimental works that use thermal barrier coating. Constant attempt has been made to obtain the optimum combinations of these parameters for the best performances of the fuel and reduction of emission. At the same time, visualization techniques for the analysis of the combustion characteristic of the additive-enhanced fuel using are being taken up as a part of upcoming research.

REFERENCES

Abedin, M. J., H. H. Masjuki, M. A. Kalam, A. Sanjid, and A. M. Ashraful. 2014. “Combustion, Performance, and Emission Characteristics of Low Heat Rejection Engine Operating on Various Biodiesels and Vegetable Oils.” *Energy Conversion and Management* 85. Elsevier Ltd: 173–189. doi:10.1016/j.enconman.2014.05.065.

Abedin, M. J., H. H. Masjuki, M. A. Kalam, A. Sanjid, S. M.Ashrafur Rahman, and B. M. Masum. 2013. “Energy Balance of Internal Combustion Engines Using Alternative Fuels.” *Renewable and Sustainable Energy Reviews* 26. Elsevier: 20–33. doi:10.1016/j.rser.2013.05.049.

ASTM. 2007. “Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester.” *Annual Book of ASTM Standards* i: 1–10. doi:10.1520/D0092-12B.

Bengtsson, P., T. Ericsson, and J. Wigren. 1998. “Coated with a Thick Thermal Barrier Coating Thermal Shock Testing of Burner Cans.” *Journal of Thermal Spray Technology* 7 (3): 340–348. doi:10.1361/105996398770350828.

Beyerlein, Steven W., and Stanislaw Wojcicki. 1988. “A Lean-Burn Catalytic Engine.” In . doi:10.4271/880574.

British Standard Section. 2000. “Designation: D445 − 17a Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity) 1” 71 (1). doi:10.1520/D0445-17A.

Cao, X. Q., R. Vassen, and D. Stoever. 2004. “Ceramic Materials for Thermal Barrier

Coatings.” *Journal of the European Ceramic Society* 24 (1): 1–10. doi:10.1016/S0955-2219(03)00129-8.

Chan, S. H., and K. A. Khor. 2000. “Effect of Thermal Barrier Coated Piston Crown on Engine Characteristics.” *Journal of Materials Engineering and Performance* 9 (1): 103–109. doi:10.1361/105994900770346358.

Hejwowski, Tadeusz. 2010. “Comparative Study of Thermal Barrier Coatings for Internal Combustion Engine.” *Vacuum* 85 (5). Elsevier Ltd: 610–616. doi:10.1016/j.vacuum.2010.08.020.

Hoseini, S. S., G. Najafi, B. Ghobadian, Rizalman Mamat, Nor Azwadi Che Sidik, and W. H. Azmi. 2017. “The Effect of Combustion Management on Diesel Engine Emissions Fueled with Biodiesel-Diesel Blends.” *Renewable and Sustainable Energy Reviews* 73 (January): 307–331. doi:10.1016/j.rser.2017.01.088.

Jung, Heejung, David B. Kittelson, and Michael R. Zachariah. 2005. “The Influence of a Cerium Additive on Ultrafine Diesel Particle Emissions and Kinetics of Oxidation.” *Combustion and Flame* 142 (3): 276–288. doi:10.1016/j.combustflame.2004.11.015.

Kamo, Roy, Nagesh S. Mavinahally, Lloyd Kamo, Walter Bryzik, and Earnest E. Schwartz. 1999. “Injection Characteristics That Improve Performance of Ceramic Coated Diesel Engines.” In . doi:10.4271/1999-01-0972.

Kannan, G. R., R. Karvembu, and R. Anand. 2011. “Effect of Metal Based Additive on Performance Emission and Combustion Characteristics of Diesel Engine Fuelled with Biodiesel.” *Applied Energy* 88 (11). Elsevier Ltd: 3694–3703. doi:10.1016/j.apenergy.2011.04.043.

Karikalan, L., & Chandrasekaran, M. (2017). "Performance and pollutants analysis on diesel engine using blends of Jatropha Biodiesel and Mineral Turpentine as fuel". International Journal of Environmental Science and Technology, 14(2), 323-330. doi.org/10.1007/s13762-016-1147-4

Lima, C. R C, and J. M. Guilemany. 2007. “Adhesion Improvements of Thermal Barrier Coatings with HVOF Thermally Sprayed Bond Coats.” *Surface and Coatings Technology* 201 (8): 4694–4701. doi:10.1016/j.surfcoat.2006.10.005.

Lima, C R C, and R Exaltação Trevisan. 1999. “Temperature Measurements and Adhesion Properties of Plasma Sprayed Thermal Barrier Coatings.” *Journal of Thermal Spray Technology* 8 (June): 323–327. doi:10.1361/105996399770350548.

MohamedMusthafa, M., S. P. Sivapirakasam, and M. Udayakumar. 2011. “Comparative Studies on Fly Ash Coated Low Heat Rejection Diesel Engine on Performance and

Emission Characteristics Fueled by Rice Bran and Pongamia Methyl Ester and Their Blend with Diesel.” *Energy* 36 (5). Elsevier Ltd: 2343–2351. doi:10.1016/j.energy.2010.12.047.

Patnaik, Pragyan P., Shakti P. Jena, Saroj K. Acharya, and Harish C. Das. 2017. “Effect of FeCl3and Diethyl Ether as Additives on Compression Ignition Engine Emissions.” *Sustainable Environment Research* 27 (3). Elsevier Ltd: 154–161. doi:10.1016/j.serj.2017.01.002.

Pundir, B. P. 2007. *Engine Emissions : Pollutant Formation and Advances in Control Technology /*. Oxford, U.K. : Alpha Science International Ltd.,. https://searchworks.stanford.edu/view/7196858.

Ramalingam, Senthil, Silambarasan Rajendran, and Pranesh Ganesan. 2016. “Performance Improvement and Emission Control in a Direct Injection Diesel Engine Using Nano Catalyst Coated Pistons.” *Biofuels* 7 (5): 529–535. doi:10.1080/17597269.2016.1168020.

Sajith, V., C. B. Sobhan, and G. P. Peterson. 2010. “Experimental Investigations on the Effects of Cerium Oxide Nanoparticle Fuel Additives on Biodiesel.” *Advances in Mechanical Engineering* 2010. doi:10.1155/2010/581407.

Shaisundaram, V. S., M. Chandrasekaran, S. Mohan Raj, R. Muraliraja, and T. Vinodkumar. 2018. “Control of Carbon Dioxide Emission in Automobile Vehicles Using CO $_2$ Scrubber.” *International Journal of Ambient Energy* 750 (January): 1–5. doi:10.1080/01430750.2017.1422149.

Sivakumar, G., and S. Senthil Kumar. 2014. “Investigation on Effect of Yttria Stabilized Zirconia Coated Piston Crown on Performance and Emission Characteristics of a Diesel Engine.” *Alexandria Engineering Journal* 53 (4). Faculty of Engineering, Alexandria University: 787–794. doi:10.1016/j.aej.2014.08.003.

Skillas, G., Z. Qian, U. Baltensperger, U. Matter, and H. Burtscher. 2000. “Influence of Additives on the Size Distribution and Composition of Particles Produced by Diesel Engines.” *Combustion Science and Technology* 154 (1): 259–273. doi:10.1080/00102200008947279.

Stanmore, Brian, Jean-François Brilhac, Patrick Gilot, and P. Gilot. 1999. “The Ignition and Combustion of Cerium Doped Diesel Soot.” In . doi:10.4271/1999-01-0115.

Valentine, James M., Jeremy D. Peter-Hoblyn, and G. K. Acres. 2000. “Emissions Reduction and Improved Fuel Economy Performance from a Bimetallic Platinum/Cerium Diesel Fuel Additive at Ultra-Low Dose Rates.” In . doi:10.4271/2000-01-1934.