EFFECTS OF CERIUM OXIDE ON THE PERFORMANCE AND EMISSION CHARACTERISTIC OF VARIABLE COMPRESSION RATIO IGNITION ENGINE USING BIODIESEL FROM WASTE MUSTARD OIL

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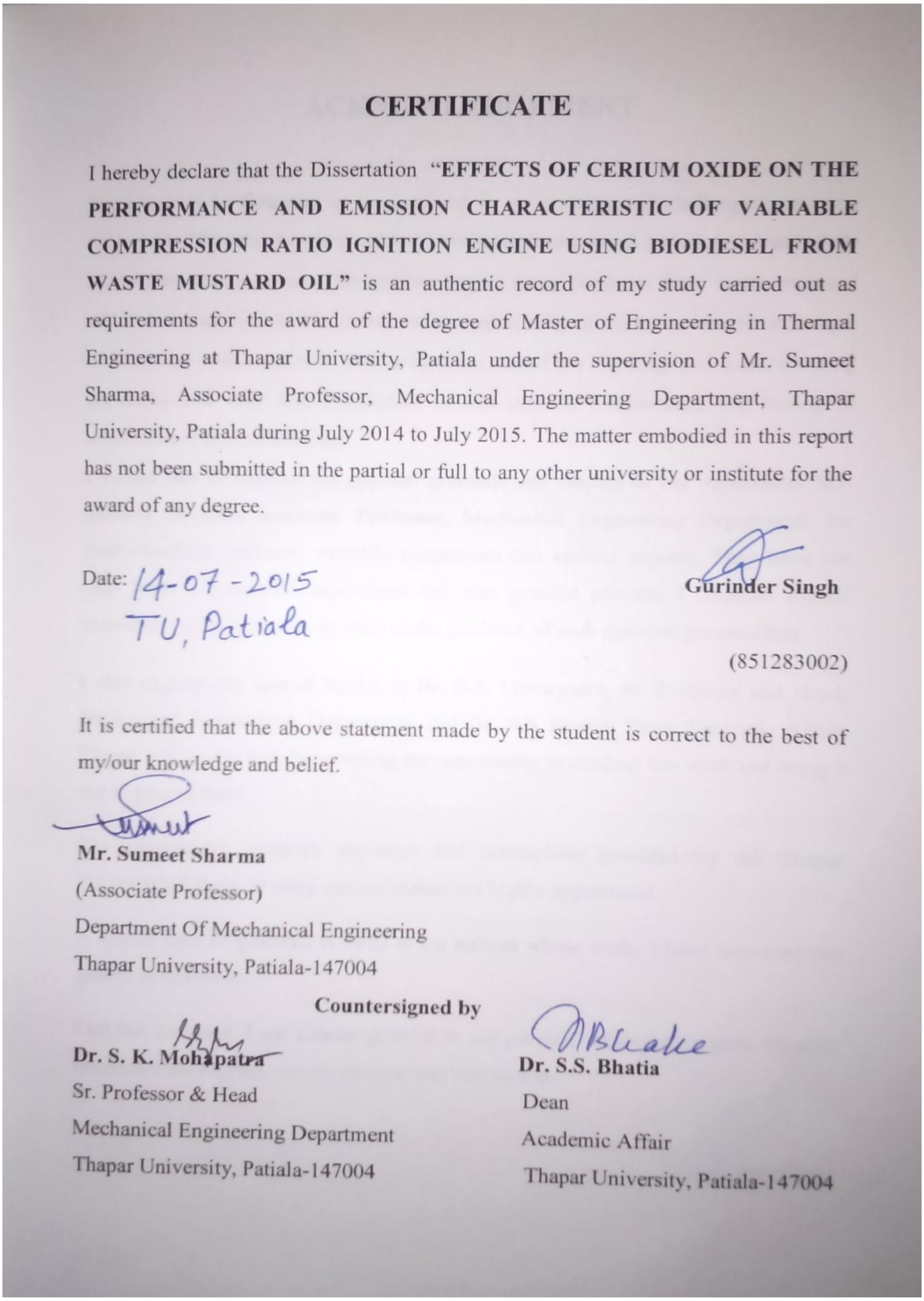

CERTIFICATE

I hereby declare that the Dissertation **"EFFECTS OF CERIUM OXIDE ON THE PERFORMANCE AND EMISSION CHARACTERISTIC OF VARIABLE COMPRESSION RATIO IGNITION ENGINE USING BIODIESEL FROM WASTE MUSTARD OIL"** is an authentic record of my study carried out as requirements for the award of the degree of Master of Engineering in Thermal Engineering at Thapar University, Patiala under the supervision of Mr. Sumeet Sharma, Associate Professor, Mechanical Engineering Department, Thapar University, Patiala during July 2014 to July 2015. The matter embodied in this report has not been submitted in the partial or full to any other university or institute for the award of any degree.

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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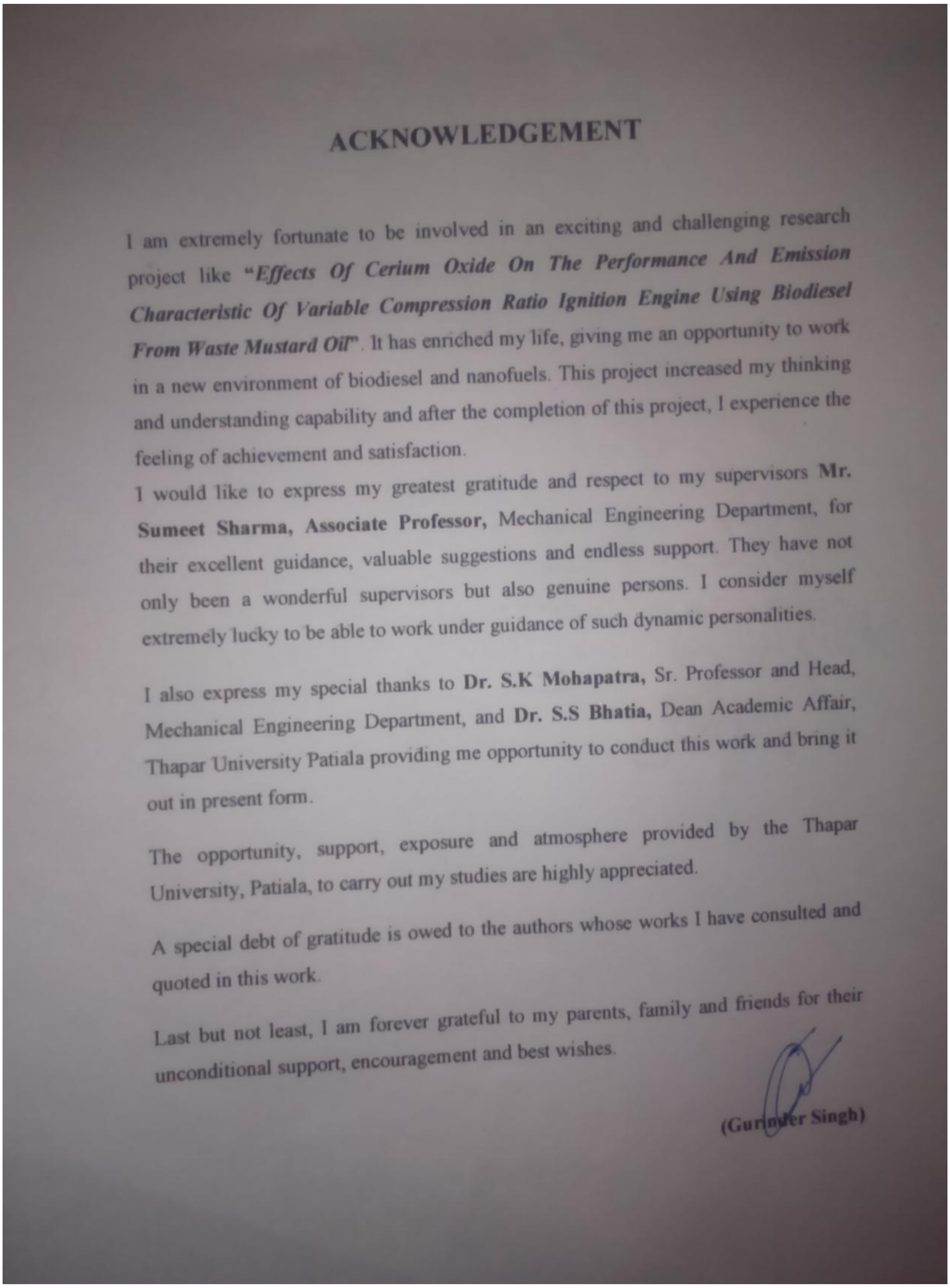

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ABSTRACT

The limited fossil fuel resources along with the need to reduce emissions are major impulse to the development of alternative fuel. The heavy vehicular density in big cities and different operating conditions of CI engine are the alarming problem of emissions. In recent research biodiesel has been developed as an alternative fuel for CI engine. Biodiesel have shown slightly lower performance and reduction in SOx, CO, HC and CO_2 as compare to diesel. But formation of NOx with biodiesel fuel was observed higher. After the advent of nanotechnology nanofuels prepared with nanoparticles has become interesting field of research topic around the world. Nanofuels have shown better improvement in combustion, performance and emission characteristics of CI engine. In this present work, nanofuels were prepared by adding the cerium oxide nanoparticles to the biodiesel. Biodiesel was manufactured from waste mustard oil using transesterification process. Nanofuels were prepared with high speed ultrasonication and agitation process to increase the stability.

The experiments were conducted on variable compression ignition single cylinder four stroke diesel engine at constant 1500 RPM to evaluate the influence of cerium oxide nanoparticles. The load and compression ratio was varied from 0 to 6 kg and 14 to 18 on the engine. The concentration of nanoparticles was dispersed 50 ppm to the 10% and 15% biodiesel in base fuel diesel. The Cetyl Trimethyl Ammonium Bromide (CTAB) was used as surfactants. The properties of different biodiesel blends such as calorific value , flash point, and viscosity were also measured as per IS standards. Experiments were performed using neat diesel and different blends of biodiesel such as D100, B10, B10$CeO_2$50, B15 and B15$CeO_2$50. The BP, BSFC, BTE, EGT, CO, NOx and HC parameters were compared to pure diesel. Results concluded that cerium oxide blended biodiesel blends considerably improve the performance parameters and decline the harmful emissions especially NOx.

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Nomenclature

ASTM	American society of testing and Petroleum
BMEP	Brake mean effective pressure
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
BTDC	Before top dead centre
CI	Compression ignition
CNT	Carbon Nanotubes
CO	Carbon monoxide
CO_2	Carbon dioxide
CR	Compression ratio
DI	Direct injection
EGT	Exhaust gas temperature
HC	Hydrocarbon
IC	Internal combustion
NO, NO_2 and NO_x	Oxide of nitrogen
PM	Particulate Matter
PPM	Parts per million
RPM	Revolution per minute
SFC	Specific fuel consumption
TDC	Top dead centre
D100	0% biodiesel + 100% diesel (% by vol.)

B10	10% biodiesel + 90% diesel (% by vol.)
B15	15% biodiesel + 85% diesel (% by vol.)
B10$CeO_2$50	10% biodiesel + 90% diesel + 50 PPM CeO_2 (% by vol.)
B15$CeO_2$50	10% biodiesel + 90% diesel + 50 PPM CeO_2 (% by vol.)
CeO_2	Cerium oxide nanoparticles

CHAPTER-1

INTRODUCTION

Biodiesel refers to any diesel fuel alternative derived from renewable biological resource. More specifically, biodiesel is defined as oxygenated, sulfur-free, biodegradable, non-toxic and eco-friendly alternative diesel oil. Chemically, it can be defined as a fuel composed of mono-alkyl esters or methyl esters of long chain fatty acids derived from renewable sources, such as vegetable oil, animal fat and used cooking oil which is designated as B100 and also they meet the special requirements such as the ASTM and the European standards. The conversion of vegetable oils into biodiesel is an effective way to overcome all the problems associated with the vegetable oils. Dilution, micro emulsification, pyrolysis and transesterification are the four techniques applied to solve the problems encountered with the high fuel viscosity. Transesterification is the most common method and leads to mono alkyl esters of vegetable oils and called biodiesel when used for fuel purposes.

1.1 Need of Biodiesel

The large increase in number of vehicles in recent years has resulted in great demand for petroleum products. The depletion of fossil fuel reserves and rising oil prices would cause a major impact on the transportation sector. To meet ever increasing energy requirements, there has been increasing interest in alternative fuels to provide a suitable diesel oil substitute for internal combustion engines. As a result biodiesel seem a very promising alternative to diesel oil since they are renewable, directly used in diesel engine without any major modification in diesel engine and show almost similar properties like diesel. India is one of the biggest petroleum product consuming and importing countries.

India imports about 70 percent of its petroleum demands. Currently Indian annual requirement for petroleum products is about 120 million metric tons of which the diesel consumption is approximately 40 million tones [1]. The United States alone consumes about 21 million barrels of oil per day, of which, about 65% is used in transportation, while the world’s oil consumption amounts to 90 million barrels per day [2].

Diesel engines are usually employed in heavy duty vehicles which are used for transportation and agricultural purposes. It was reported that Turkey's demand for diesel fuel in 2006 is 12.07 million tones, which is higher than the unleaded gasoline demand of 3.88 million tones [3]. Forecasts are there which say that transport on a global scale will increase demand for conventional fuels with up to a maximum annual growth of 1.3% up to 2030. This would result in a daily demand of around 18.4 billion liters (up from around 13.4 billion liters per day in 2005) [The Royal Society, 2008].

Waste vegetable oil has been proposed by many researchers as the best source of alternative oil to produce biodiesel. According to the United States Environmental Protection Agency (EPA), restaurants in the US produce about 300 million US gallons (1,000,000 m^3) of waste cooking oil annually.

Further it is seen that exhaust of automobiles is one of the major contributors to the world's air pollution problem. Recent research and development in this area has made major reductions in engine emissions, but growing population and greater number of automobiles are clearly an indication that the problem will persist for many years to come. The use of biodiesel has shown substantial reduction in unburned HC, PM and CO emissions [8].

The air pollution in India has been recorded as one of the highest in the world. In 2005-06 there were 8.9M vehicles sold and in five years this number has scaled to 15M (in 2010-11) [5]. The city of Delhi, which is the capital of India, is one of the ten most polluted cities in the world, as pointed out by the World Health Organization. The number of vehicles currently running on the road in Delhi is around 5.6 million, as per the Economic Survey of Delhi [4].

It is of importance to quote here that various laws were passed in the United States and in other industrialized countries which limit the amount of exhaust emissions and give the guidelines for allowable limits. This has put a major restriction on automobile engine development during the 1980s and 1990s. For example, Euro 5 standard for passenger cars has reduced NOx and PM emission from 0.25 and 0.025 g/km to 0.10 and 0.005 g/km [6].

Table 1.1: Emission Standards for Gasoline Vehicles (GVW ≤ 3,500 kg) in India, g/km [5]

Standards	Reference	CO	HC	HC+NOx	NOx
2000(year)	Euro 1	2.72-6.90	-	0.97-1.70	-
Bharat stage 2	Euro 2	2.2-5.0	-	0.5-0.7	-
Bharat stage 3	Euro 3	2.3 4.17 5.22	0.20 0.25 0.29	-	0.15 0.18 0.21
Bharat stage 4	Euro4	1. 1.81 2.27	0.1 0.13 0.16	-	0.08 0.10 0.11

The exhaust gases from the automobiles affect human body and give rise to contagious diseases. Besides substantial CO_2 emissions, significant quantities of CO, HC, NOx, PM and other air toxins are emitted from automobiles in the atmosphere, which cause serious health problems like cardio vascular disorder, nervous system disorder, vision and judgment impairment, nausea and vomiting. Besides, this it also reduces a person’s capability to reproduce. More severe problems include impairment of lung functioning, eye, nose and throat irritations, immune system disorder and cancer.

Due to the problems and situation we have encountered now, we need to overcome challenges as well as an opportunity to look for substitutes of fossil fuels for both economic and environmental benefits for the society and the country itself.

1.2 Fuel properties

Some of the properties of the biodiesel are discussed below:-

Density

Density of biodiesel is larger than that of diesel (specific gravity 0.88 compared to 0.84 for diesel fuel) therefore biodiesel should be mixed at the top of diesel for proper mixing. If bio-diesel is first put at the bottom and then diesel fuel is added, it will not mix properly.

Kinematic viscosity

Viscosity is an important physical property of a diesel fuel and a measure of the resistance to flow. The performance of diesel fuel also greatly depends upon their viscosity. Too low a viscosity causes excessive leakage at the injection stage while too high viscosity produces coarse oil droplets which results in the formation of engine deposits owing to incomplete combustion. Diesel fuels with extremely low viscosities may not provide sufficient lubrication for the closely fit pumps and Injector plungers. Biodiesel have larger kinematic viscosity than diesel approximately 1.5 times higher. Due to this, biodiesel significantly suppresses the fuel spray evaporation and atomization process resulting in slower burning and longer combustion duration [7, 8].

Flash Point and Fire Point

Flash point of a fuel is defined as the minimum temperature at which the fuel generates just sufficient vapour to form inflammable mixture with air, as shown by the formation of momentary flame (flash) when an external source of fire is brought in contact with the vapour. The fire point is the minimum temperature at which the fuel vapour will continue to burn without external supply of flame. For the same product the fire point is higher than flash point. Fuel with flash point above 66^oC is regarded as safe. The flash point and fire point of bio-diesel is higher than the petroleum based diesel fuel. Flash point and fire point of bio-diesel blends is dependent on the flash point of the base diesel fuel used and increase with percentage of bio-diesel in the blend. Thus when it comes to storage biodiesel is safer than conventional diesel [7].

Cloud point and pour point

Cloud point is defined as the temperature at which the oil becomes cloudy when it is cooled in specified manner. This temperature is higher than the pour point (usually 5^oC to 6^oC). The cloud point becomes significant than pour point in diesel fuel where the formation of wax crystals can plug the filters in the diesel injection system and stop the flow even if the oil is above the pour point. The pour point is defined as the temperature 2.8^{o}C higher than that at which the oil ceases to flow when cooled and tested according to the prescribed conditions. The cessation of flow results from an increase in viscosity in diesel fuel. Pour point may also be reduced by increasing the proportions of lighter hydrocarbons in oil. Biodiesel generally has higher cloud point and pour point than diesel fuel which make it very sensitive to cold weather conditions and results in the difficulty of cold starting [7,8].

Calorific value

It is the total quantity of heat liberated by completely burning of one unit mass of fuel. The calorific value of a substance is the amount of energy released when the substance is burned completely to a final state and has released all of its energy. The calorific value of fuel is determined by Bomb calorimeter [7].

Ash content

It describes the amount of inorganic contaminants such as abrasive solids, catalyst residues and the concentration of soluble metal soaps contained in a fuel sample. These compounds are oxidized during the combustion process to form ash which is connected with engine deposits. The higher the ash content the higher is the risk of engine damage.

Carbon residue content

This property is important for oil used in diesel engine. The heavier complex compounds on decomposition form some carbonaceous deposits known as carbon residue [7].

Cetane Number

Higher the cetane number better are the ignition properties of the fuel. The ignition quality of diesel fuel is measured in a standard engine by matching against blends of two reference fuels n-paraffin and aromatic expressed in the term of cetane number.

High speed engines above 1500 rpm need high cetane number 45-50. For low engine speeds 25-30 cetane numbers may suffice. The CN is a measure of the ignition quality of diesel fuels, and a high CN implies short ignition delay. The CN of biodiesel is generally higher than conventional diesel. Due to higher CN, combustion efficiency of biodiesel is higher.

1.3 Specification of Biodiesel

Standards play vital role for the manufacturers, suppliers and users of bio-fuels. Authorities need approval standards for the evaluation of safety, risks and environmental protection. Conventionally standards and codes for products have been developed, largely by examining existing standards and codes in different countries and then writing standards for own country. A worldwide survey of bio-diesel specification was done and an attempt was made to understand the objective behind them before proposing a norm for India. The main components, which represent the quality of biodiesel, are monoalkylesters, dialkyl esters, residual vegetable oil, free glycerin, reactant alcohol, free fatty acids and the residual catalyst. In December 2001, American Society of Testing and Materials (ASTM) issued a specification (D6751) for biodiesel (B100) which is written in tabular form as in Table 2.

Table 1.2: Properties of biodiesel according to ASTM standards [9]

Fuel property	ASTMD6751 (Biodiesel)	Commercial diesel fuel
Density (kg/m^3)	--------------	750–840
Kinematic viscosity(mm^2/s)	1.9-6.1	1.9-4.1
Flash point (^{o}C)	>130	67–85
Pour point (^{0}C)	-15 to 10	19–13
Cloud point(^{0}C)	-3 to 12	<10
Cetane Number	47	40–46
Higher heating value(kJ/kg)	>33000	42000
Ash content (%)	<0.02max	0.008–0.010
Carbon residue (%)	<0.05	0.35–0.40
Sulfur content (%)	0.05% by mass, max.	0.35–0.55
Water contents (%)	0.050% by vol., max.	0.02–0.05

1.4 Performance and Emission characteristics

1.4.1 Performance Characteristics of C.I Engines

The performance of an engine is an indication of degree of success for with which it is doing its assigned job.

The degree of success is compared on the basis of the following.

a. Brake power developed or BMEP.
b. Specific fuel consumption (kg/ kW-hr).
c. Specific power output (kW/ kg of engine weight).
d. Specific weight
e. Pollution from the engine.

The application of the engine decides the relative importance of these parameters. The specific power output is more important for marine engines whereas specific fuel consumption is more important for industrial engines. The basic parameters which are considered for evaluating the engine performance are:

a. Indicated power.
b. Mechanical efficiency.
c. Thermal efficiency.
d. Specific fuel consumption.
e. Volumetric efficiency.
f. Exhaust emission
g. Fuel-air ratio

1.4.2 Engine performance and emission characteristics of biodiesel

Biodiesel has low calorific value, on weight basis because of presence of substantial amount of oxygen in the fuel but at the same time biodiesel has a higher specific gravity (0.88) as compared to diesel (0.85) so overall effect is approximately lower energy content per unit volume. Thermal efficiency of an engine operating on biodiesel is generally better than diesel. Brake-specific fuel energy consumption (BSEC) is a more suitable parameter compared to brake-specific fuel consumption (BSFC) for comparing fuels having different calorific values and densities. The hydrocarbon emissions are much lower in case of biodiesel as compared to diesel. This is also due to oxygenated nature of biodiesel where more oxygen is available for burning and reducing hydrocarbon emissions in the exhaust. CO is a toxic combustion product resulting from incomplete combustion of hydrocarbons. Since biodiesel is free from sulfur hence less sulfate emissions and particulate drop is found in the exhaust. Because of the absence of sulfur biodiesel reduces the problem of acid rain due to transportation fuels. Many researchers have evaluated the engine performance of different biodiesel blends. Yage Di et al. investigated the waste cooking oil methyl esters in the diesel engine. They observed that the engine performance, especially the brake power output and exhaust emission characteristics improved significantly. The brake thermal efficiency of biodiesel was found to be slightly higher as compared to diesel at medium and higher loading conditions. For combustion and emission characteristic slightly shorter ignition delay and slightly reduction was found in major emission like HC and CO while NOx and NO_2 increases, as shown in the Table 3.

Table1.3: The performance and emissions of diesel and B100 [8]

Parameter / **Fuel**	**BTE (%)**	**BSFC(g/kW-hr)**	**HC(ppm)**	**CO(ppm)**	**NOx(ppm)**
Diesel	34.44	239.2	122	363	590
B100	36.81	260.7	80	316	680

1.5 Compression ignition engine[10]

The compression ignition engines draw only fresh air into the cylinder during induction stroke and then on their return stroke compresses this charge into 1/15 to 1/22 of the unswept volume until the temperature is raised well in excess of 550°C. Just before the piston reaches the end of the compression stroke an accurately metered quantity of fuel is injected into the cylinder at 350 bar pressure or more. The finely atomizing and well charged fuel spray mixes with the hot air causing it to ignite and burn rapidly. The time for injecting the fuel over a 40° crank angle movement at 5000 RPM is 0.000133 min.

Air combustion in a CI engine is an unsteady process occurring simultaneously into the engine when it is unthrottled, with engine torque and power output controlled by the amount of fuel injected per cycle.

1.5.1 Classification of compression ignition combustion chamber

The compression ignition combustion chambers can be subdivided into two categories as given below:

(a) Direct injection combustion chamber: In these types of chambers fuel is directly injected into the chambers. These chambers are normally used for large (10 to 16 liter) low to medium speed (up to 2500 rpm) commercial vehicle diesel engine where fuel consumption is low and torque output is high. Direct injection volumetric combustion chamber is shown in Fig. 1.1.

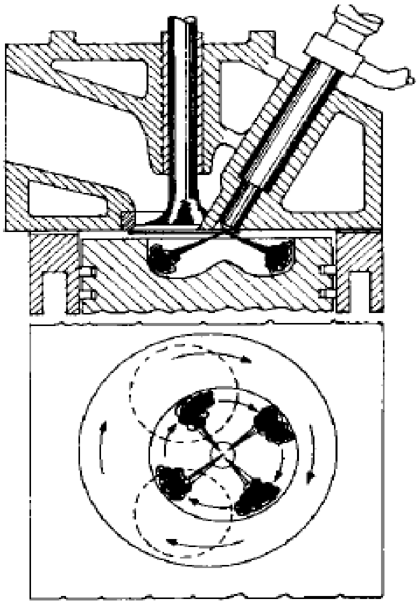

Figure 1.1: Direct injection volumetric combustion chamber [10]

(b) Indirect combustion chamber: In this chamber combustion takes place into the divided chambers. These chambers are normally used on small (1.5 to 3.5 liter) diesel car engines which can run with a clear exhaust up to 5000rpm and where a smooth low speed low noise level engine is required. Indirect combustion with swirl combustion chamber is shown in Fig 1.2.

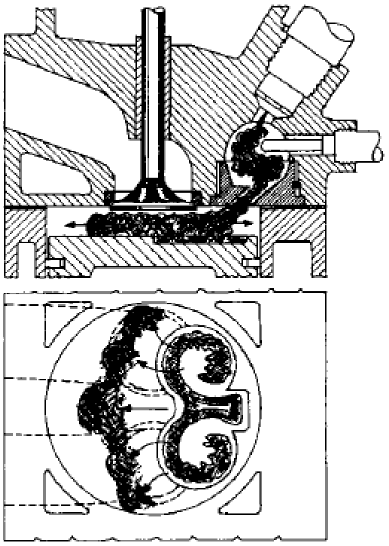

Figure 1.2: Indirect injection with swirl combustion chamber (Ricardo Cornet) [10]

1.6 Nanofluid fuel [11]

Application of nanoscale energetic metal particle additives in liquid fuel is an interesting concept yet unexplored to its full potential. Depending on the physical, chemical, and electrical properties of the added nanomaterials, nanofluid fuels can achieve better performance emission characteristics for diesel engine. Such formulated nanofuels offer: shortened ignition delay, decreased burn times and rapid oxidation, enhanced catalytic effect, microexplosion behavior which leads to complete combustion. Overall calorific value of the liquid fuel increases due to higher energy density of metal particles, eventually improving the performance of engine by boosting power output. The study of evaporation rate and ignition probability plays an important role in determining two critical properties: ignition delay and ignition temperature which characterizes the performance of a diesel engine and are also instrumental in limiting emissions.

Certain drawbacks such as strong particle aggregation, and stability and metal oxide particles may limit applications of nanofluid fuels. To overcome this problem one more chemical called surfactant is used to bind the molecules of the constituent liquids. Then a mechanical agitator and ultrasonicator are used to mix the liquids thoroughly.

1.7 Nanoparticles with biodiesel

Biodiesel is a renewable and eco- friendly alternative diesel fuel for diesel engine. Biodiesel has higher viscosity, density, pour point, flash point and cetane number than diesel fuel. Biodiesel is an oxygenated fuel which contains 10–15% oxygen by weight. This fact lead biodiesel to total combustion and reduces the exhaust emissions particulate matter (PM), carbon monoxide (CO), sulfur oxides (Sox), and unburned hydrocarbons (HC) as compare to diesel fuel. But due to the lesser energy content and complete combustion, it gives poor performance and shown drastic increasement in NOx. So to improve the performance and emission especially NOx and particulate matter of diesel and diesel blended with biodiesel nanofuels have become an essential part of today's fuels. With use of fuel additives in the blend of biodiesel and diesel fuelled in CI Engine which furthers more improve performance, combustion, and diminish emission characteristics and also improved fuel properties which enhance the combustion characteristics.

1.8 Effect of nanoparticle on CI Engine parameters

1.8.1 Effect on Performance [11]

Addition of nanoparticles in diesel and diesel-biodiesel blends not only enhances the calorific values but also promotes complete combustion due to higher evaporation rates, reduced ignition delay, higher flame temperatures and prolonged flame sustenance. All these factors support the full release of thermal energy thereby leading to higher brake thermal efficiency and lower BSFC. This phenomenon could have led to catalytic combustion, and in turn enhanced the thermal efficiency of the diesel engine. Nanoparticle addition to the fuel decreased ignition delay and consequences of ignition delay lowered the peak cylinder pressure.

1.8.2 Effect on Emissions [12]

Air pollution nowadays serious problem in many countries some researchers are working in the same way to reduce engine emissions. The increasingly use of CI engine vehicles has lead to deterioration of the quality of air to a level. One prospective method to solve this issue is to use the fuel additives. Emissions of

Particulate Matter and Oxides of Nitrogen are the focus of today's diesel emission control technologies. Nanometal oxide additives are reported to be effective in lowering diesel emissions. The principle of this additive action consists of a catalytic effect on the combustion of hydrocarbons. Use of transition (or) noble metals in the form of fuel additives lowers the soot ignition temperature. The metal additive in the diesel fuel changes the cetane number (by about 1–1.2%) and affects combustion and emissions. Fuels with a high cetane number have smaller premixed fuel portions and lower NO emissions for the same BMEP compared to lower cetane number. Some metal-based additives are reported to be effective in lowering diesel emissions. They may reduce diesel emissions by two ways. First, the metals either react with water to produce hydroxyl radicals, which enhance soot oxidation, or react directly with carbon atoms in the soot, thereby lowering the oxidation temperature.

1.9 TYPES OF NANOMATERIAS USED IN FUEL

Later, many experimental studies have been carried out on performance and emission of CI engine using a variety of nanomaterials like:

- Oxide ceramics: alumina (Al2O3), copper oxide, (CuO), magnetite (Fe3O4) , zinc oxide (ZnO), manganese oxide (MnO) and ceria (CeO_2)
- Metals: copper (Cu), iron (Fe), Cobalt (Co), Magnesium (Mn), Boron (Br) and aluminum (Al)
- Single and multi-walled carbon nanotubes (SWCNTs, MWCNTs)

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CHAPTER 2

LITERATURE REVIEW

In this chapter many research papers were studied to formulate the problem. Research topic is related to the nanofuels. The nanofuels were prepared by adding nanoparticles to the diesel-biodiesel blends. The experiments were performed at variable compression engine. In this chapter lot of research papers were studied which are related to synthesis of nanoparticles, addition of nanoparticles to the biodiesel blends, effect of nanoparticles on fuel properties, effect on combustion performance and emission characteristics. Some papers were reviewed related to the biodiesel manufacturing, performance and emission characteristics.

2.1 LITERATURE REVIEW

A. Selvaganapthy et al. [1] evaluated the performance and emission characteristic of single cylinder four stroke vertical water cooled diesel engine using diesel fuel and the zinc oxide nano particles which were mixed with the diesel fuel at the rate of 250 ppm and 500 ppm. The obtained particle size range was from 24-71 nm. A magnetic stirrer was used to disperse the nano particles into the diesel and laser spectrometer was used to measure the dispersion. The higher cylinder peak pressure was observed for blend of nano particles with diesel. The 69 bar cylinder peak pressure for diesel fuel was attained at a crank angle of 5° after TDC, 75.6 bar was obtained for diesel fuel blended with 250 ppm of Zinc Oxide at crank angle of 2° after TDC and 78 bars was achieved at crank angle of 2° after TDC for diesel fuel blended with 500ppm of Zinc Oxide. The addition of zinc oxide further increased the heat release rate by 12.8% for 250ppm concentration of zinc oxide and20% for 500ppm of Zinc Oxide. The NOx emission was lower for the neat diesel compared to all the fuel blends. Least smoke opacity was observed for diesel fuel which was 5.2% at low load and 27.2% at full load while compared to the blended fuel. The brake thermal efficiency was found to improve by 2.71% with 250ppm ZnO and 4.53% for 500ppm ZnO.

Ajin C. Sanjeevan et al. [2] had conducted an experiment on a naturally aspirated four stroke single cylinder water-cooled compression ignition engine operating at rated speed of 1500 RPM to investigate the catalytic activity of cerium oxide. The performance and emission were compared with diesel and diesel having cerium oxide nano particle with 5, 15, 25 and 35PPM concentration. Characterization technique such as EDS, XRD and TEM were used for studying the properties of cerium oxide nano particle prepared by precipitation method and surfactant dodecenyl succinic anhydride was added in diesel to obtain a stable suspension which had HLB Value 1.34. It was seen that the viscosity, flash and fire point increases with addition of nano particle. The load tests were conducted by varying the dosing levels of cerium oxide nano particle in diesel, the brake thermal efficiency was found to be increase at the dosing level of 35 ppm of cerium oxide with 2% DDSA. The hydrocarbon emission decreased on addition of catalytic nano particle by about 40 to 45%, especially at higher load. The NOx emission was found to decrease by a maximum of 30% on the addition of cerium oxide nano particle in diesel especially at higher loads and further reduction up to 50% with the addition of 5% volume fraction of surfactant treated nano particle.

V. Arul Mozhi Selvan et al. [3] investigated the performance and emission characteristics of neat diesel and diesel-biodiesel-ethanol blends with 25 PPM and 32 nm size cerium oxide as fuel borne additive on a single cylinder four stroke variable compression water cooled engine at the compression ratio of 19. The phase separation between diesel and ethanol was prevented by adding biodiesel. The turbidity procedure was used to assess the stability of the resulting suspension. All the results were plotted against brake mean effective pressure (BMEP). The lower BSFC was observed for Cerium oxide blend of neat diesel. The higher brake thermal efficiency was observed for neat diesel. The highest peak pressure 10.2Mpa was found for neat diesel blends with cerium oxide. The addition of cerium oxide further decreased the CO, HC emission when compared to neat diesel. The NOx emission was lower for the neat diesel as compared to all the fuel blends. The least smoke absorption coefficient was observed as 1.273 for cerium oxide blended diesel-biodiesel-ethanol blends at BMEP of 0.44MPa.

V. Sajith et al. [4] had studied the influence of dosing level ranging from 20 to 80 PPM of cerium oxide nano particles in biodiesel derived from jatropha, on a single cylinder water-cooled direct injection diesel engine operating at 1500 RPM. The physiochemical properties, performance and emission characteristics were measured. The size of nano particle was 10 to 20 nm and density was 7.13g/ml. The results so obtained were plotted against the load on test engine. Increasing trend was seen in the physiochemical properties of fuel like flash point, viscosity and volatility with addition of nano particle. The results concluded that an average reduction of 25% to 40% in the hydrocarbon emission was obtained for the additive dosing level ranging from 40 to 80 PPM of the additive. The NO_x emission was found to be generally reduced by 30% on the addition of cerium oxide nano particle to biodiesel with dosing level of 80 PPM. The reduction influence of the fuel additive on carbon monoxide emission was not so prominent.

Rakhi N. Mehta et al. [5] Investigated the burning characteristics, engine performance and emission parameters of a single-cylinder Compression Ignition engine using nano fuels which were formulated by sonicating nano particles of aluminum (Al) having 30-60nm, iron (Fe) 5-150 nm and boron (Bo) 80-100 nm in size in base diesel with 0.5wt% and 0.1wt% Span80 as a surfactant for stable suspension. The nano fuels reduced ignition delay, longer flame sustenance and agglomerate ignition by droplet combustion mechanism test. Peak cylinder pressures decreased at higher load conditions and were registered as 55 ,59, 60 and 62 bars for A1, Bo, Fe and diesel respectively. Specific fuel consumption was reduced by 7% with A1 in comparison to diesel. Exhaust gas temperatures of A1, Fe, and Bo rose by 9%, 7% and 5% respectively, resulting into increase in brake thermal efficiencies by 9%, 4%, and 2% as compared to diesel at higher loads. A wet Whatman filter paper was adopted to collect the soot particles and increase in weight by 12%, 9%, and 8% was observed for Fe, Bo and A1 nano fuels, respectively as compared to diesel. At higher loads, the emission study showed a decline of 25–40% in CO (vol.%), along with a drop of 8% and 4% in hydrocarbon emissions for A1 and Fe nano fuels respectively. Due to elevated temperatures a hike of 5% and 3% was observed in NOx emission with A1 and Fe.

S. Karthikeyan et al. [6] had conducted the experiments for low ,medium and heavy loads at rated speed 1500 RPM with injection pressure of 220 bar on a single cylinder direct injection diesel engine to evaluate the performance and emission characteristics of Promolin Stearin wax oil 20%(B) biodiesel blended with 80% diesel (D). The average particle size of the zinc oxide was less than 100nm and concentration was vary 50 PPM and 100 PPM. All the results were shown against the BMEP. Owing to the energetic materials zinc oxide additive improved the calorific value of the blends but in other properties did not observe any significant improvement. Due to the complete combustion took place in the combustion chamber BSFC was decreased and BTE was improved with the increase in the prescribed amount level of ZnO in the fuel. The CO and HC had appreciably declined with the increase in the dosing level of the nano particle as compared to B20. The NOx emissions of all blended fuels did not have any significant effect.

M. A. Lenin et al. [7] investigated the effect of metal additives MnO (200 mg/l) and CuO (200 mg/l) doped in diesel on performance and emission characteristics of single cylinder diesel engine. Synthesis was done with sol–gel method for nano fuel preparation. The ranges of nano particle between 50-210nm was observed with SEM. All the results were revealed against the load. The improvement in fuel properties (viscosity, flash point and fire point) was noted due to the addition of nano metal oxide. Brake thermal efficiency was raised marginally by 4% from the diesel fuel. The HC emissions were highest at lower load. At full load it was seen that 1% decrease in the HC emission, it was observed that manganese has the stronger effect in reducing the diesel exhaust emissions. The exhaust emission measurements for the fuel with manganese additive showed that CO was decreased by 37%, and NOx was reduced by 4%.

Karoon Fangsuwannarak et al. [8] had compared effect of the different fuel additives as polymer based-bio-solution, natural organic based-bio-solution and nano-titanium metalloid (TiO_2) compound on the performance parameters and exhaust emissions of a pickup Diesel engine, operating on commercial Diesel fuel (D) and B5 palm biodiesel (95% D+5% palm oil). TiO2 was used as the nano particle. The recommended concentration of the nano particle from their producer was used to prepare the blend. All the results were plotted against engine speed. According to his results, exhaust gas temperature was observed to increases with increase of speed. It was found that TiO_2 had reduced the specific fuel consumption and increased engine power for pure diesel by 13.22% and7.78% respectively. However the NO_x emission for commercial diesel blended with nano particle fuel was effectively reduced as compared to commercial diesel and B5 blended with nano particle. In addition, at high engine speed the minimal CO emission becomes less than 55 PPM for commercial diesel blended with nano particle. TiO_2 nano particle had the most influence on the diesel fuel for reducing the CO emission with the decreasing fraction by 1% at 1500, 85% at 2000RPM, 80% at 2500 RPM and 76% at 3000 RPM as compared to neat diesel. It had no effective reduction of CO emission for blending in B5 fuel. The blend of TiO_2 based additive with diesel was provided the minimum CO_2 emission and led to the minimization of fuel consumption in comparison with diesel without additive. The basic properties of the fuel blended with TiO2 metalloid compound and bio-solution based additives were measured according to ASTM standard. It was found that TiO_2 based-additive is more effective for improving engine power than pure Diesel and B5 fuels by 7.78% and 1.36%, respectively. Meanwhile with using TiO2 additive the maximum engine torque on average is increased by 1.01% and 1.53% in the wide range between 1,700 and 3,000 rpm as compared with Diesel and B5 fuels respectively. The TiO_2 and natural organic additives was significantly effective on Diesel fuel for reducing brake specific fuel consumption reached by 13.22% and10.01%, respectively as compared with pure Diesel. Moreover, the exhaust emissions (NOx, CO and CO_2) were decreased from the engine using the TiO2 additive in Diesel fuel and natural organic additive in Diesel fuel.

M. B. Shafii et al. [9] had conducted the experiments on a four cylinder in-line four stroke compression ignition water cooled engine operating at 2200 RPM to study the performance and emission characteristics of 0,0.4,0.8(D,D+4F,D+8F) concentration of ferro fluid by volume blended with diesel to make the emulsion. Synthesis of nano particle was based on reacting iron II and III ions in an, aqueous tetra methyl ammonium hydroxide solution used to form magnetite i.e. Fe_3O_4 was produced electrostatic repulsion. The average particle diameter observed by TEM is 10 nm. Results formulated on basis of load variation which shown that fuel adding 0.4% ferro fluid to diesel increased the BTE by 3.33–6.89% relatively and adding 0.8% ferro fluid to diesel fuel increased the BTE by 5.33–12.17% relatively. Adding 0.4% ferro fluid to diesel fuel decreased BSFC by 3.23–6.45%, NOx emission by 9 to 15 PPM and adding 0.8% Ferro fluid to diesel fuel decreased the BSFC relatively by 5.06–10.85%, NO_x emission by 14 to 24 PPM. For D+4F increased CO emission by 10 to 17 PPM. Similar adding 0.8% ferro fluid to diesel fuel increased CO emissions by 21 to 42 ppm.

N. R. Banapurmath et al. [10] had conducted the test to determine the combustion, performance and emission characteristics of single cylinder four stoke direct injection diesel engine using Hinge oil methyl ester (HOME) biodiesel fuel blended with multi walled carbon nano tube (MWCNT) with 25 and 50 PPM concentration. Average particle size, bulk density, surface area and purity of CNT were 10-30nm, 0.05-017 g/cc, 350 m^2g, 95% respectively. Neat diesel was used for base line data generation for experimentation purpose also the compression ratio, injection opening pressure, injection timing was kept at 17.5, 205 bar and 23°BTDC for diesel operation and 17.5, 230 bar and 17.5° BTDC for blend of HOME-MWCNT respectively. The entire test was conducted at a constant speed of 1500 RPM and by varying the load. The result revealed that better thermal efficiency was observed for HOME-MWCNT blended fuel. The maximum brake thermal efficiency for HOME50MWCNT was 25.0% whereas it was 24% for HOME25MWCNT as compared to 23% for HOME and 28% for neat diesel at 80% load respectively. Additive blended fuel reduced the smoke opacity as compared to HOME. The observed smoke opacity for HOME25MWCNT and HOME50MWCNT was 63 and 59 HSU as compared to 78 HSU for HOME and 52 HSU for neat diesel respectively at 80% load. The NO_x emission for HOME25MWCNT was 600 PPM where it was 750 PPM for HOME50MWCNT, compared to 580 PPM for HOME and 800 PPM for neat diesel at the 80% load respectively.

S. Karthikeyan et al. [11] performed the experiments with the nanofuels of zinc oxide nanoparticles, diesel (D) and canola oil methyl ester biodiesel (B) on the single cylinder direct injection diesel engine operating at constant speed 1500rpm. The 100nm size nanoparticles used to prepare the nanofuels with 50 PPM and 100 PPM and fueled with various blends such as D80B20, D80B20ZnO50, and D80B20ZnO100 in diesel engine. The results revealed that slight improvement was observed in kinematic viscosity and calorific value. The highest cylinder pressure was achieved for additive added fuels. Among the all blends D80B20ZnO100 was released maximum heat 95.93kj/m^{3}deg. The BSFC was decreased as the dosing level increased. At higher load brake thermal efficiency was shown improving trend. It was seen that minimum CO and HC determined with the ZnO blend fuel compared to B20 while the NOx emission was found more with ZnO blended fuel.

G. R. kannan et al. [12] examined the use of ferric chloride (FeCl3) as a fuel borne catalyst (FBC) for waste cooking palm oil based biodiesel. The metal based additive was added to biodiesel at a dosage of 20μmol/L. Experiments were conducted to study the effect of ferric chloride added to biodiesel on performance, emission and combustion characteristics of a direct injection diesel engine operated at a constant speed of 1500 rpm at different operating conditions. The results revealed that the FBC added biodiesel resulted in a decreased brake specific fuel consumption (BSFC) of 8.6% whiles the brake thermal efficiency increased by 6.3%. FBC added biodiesel showed lower nitric oxide (NO) emission and slightly higher carbon dioxide (CO2) emission as compared to diesel. Carbon monoxide (CO), total hydrocarbon (THC) and smoke emission of FBC added biodiesel decreased by 52.6%, 26.6% and 6.9% respectively compared to bio diesel without FBC at an optimum operating condition of 280 bar injection pressure and 25.5^0 TDC injection timing. Higher cylinder gas pressure, heat release rate and shorter ignition delay period were observed with FBC added biodiesel at these conditions.

Ali Keskin et al. [13] had investigated the influences of tall oil biodiesel with Mg and Mo based fuel additives on single cylinder DI diesel engine at variable speed up to 3600rpm under full load conditions for performance and emission. Tall oil resinic acids were reacted with MgO and MoO2 stoichiometrically for the production of metal-based fuel additives. The additives were added into tall oil biodiesel B60 (60% biodiesel + 40% diesel fuel) at a dosage of 4 μmol/l, 8 μmol/l and 12 μmol/l for preparing test fuels. The significant effect was that both the additives shown improvement in the fuel properties. All the results were shown against the speed. The performance of engine did not change considerably with biodiesel fuels, but exhaust emission shown drastic change. Maximum increase of fuel consumption was 5.51% with B60 at 2800 rpm, and minimum increase was 3.08% with B60–8Mo at 1800 rpm. CO emissions and smoke opacity decreased by 56.42% and by 30.43%, respectively. In general, low NOx and CO2 emissions were measured with the biodiesel fuels. The Maximum reduction in CO2 observed 8.82% with B60–12Mg at 1800 rpm. In addition, in comparison with Mo-based additives, lower CO2 concentration was measured with Mg-based additive. NOx emissions were reduced with all biodiesel fuels at high engine speed. According to diesel fuel, the ratio of maximum increase is 12.78% with B60–12Mo at 2200 rpm and the maximum reduction was 23.19% with B60–8Mo at 2800 rpm, respectively.

Metin Guru et al. [14] had studied the engine performance and exhaust emissions of chicken fat biodiesel with synthetic Mg(magnesium) additive in a single-cylinder, direct injection (DI) diesel engine at full load operating conditions and different engine speeds from 1800 to 3000 rpm in the interval of 200rpm. A two-step catalytic process was selected for the synthesis of the biodiesel. Methanol, sulphuric acid and sodium hydroxide catalyst were used in the reaction. To evaluate their effects on viscosity and flash point of the biodiesel, reaction temperature, methanol ratio, type and amount of catalyst were varied as independent parameters. Organic based synthetic magnesium additive was mixed into the biodiesel blend (B10) by 12 μmol Mg. Viscosities of biodiesel with and without additive were determined with a Brookfield DV-III rheometer. The results were compared with diesel fuel (EN 590). The additive causes reductions in the flash point, viscosity and pour point were observed compared to the fuel without additive. The results revealed that, the engine torque was not changed notably of B10, while the specific fuel consumption enhanced by 5.2% due to the lower heating value of biodiesel. In-cylinder peak pressure slightly rose and the start of combustion was earlier. CO and smoke emissions decreased by 13% and 9% respectively, but NOx emission increased by 5% with the addition of biodiesel to diesel fuel.

A. Keskin et al. [15] had performed the experiment on single cylinder diesel at full load conditions with variable speed from 1,800 to 3,200 rpm with an interval of 200 rpm to determine the effect of tall oil biodiesel with cobalt (Co)-based additive for engine performance and exhaust emissions. The tall oil sample consists of 53.6% resin acids, 36.3% fattyacids, 4.5% unsaponifiables matter, and 5.6% water. Co-based additive at the rate of 4, 8, and 12μmol/l was added to mixtures of 60% tall oil methyl ester and 40% diesel fuel (T60). On the addition of additives the fuel properties like pour point and viscosity significantly decreased. Biodiesel fuels had insignificant influence on engine torque and the power output values The lowest value of specific fuel consumption were observed at 2400 rpm for the all test fuels. Specific fuel consumption values declined slightly with the addition of Co-based additive. Additive added biodiesel shown decreasing trend in CO emission which was ranged from 19.52 to 53.37%. CO2 emission values of biodiesel fuels were reduced by 7.6% than diesel. The Co-based additive did not affect CO2 concentration Higher NOx emissions were measured at low engine speed whereas lower NOx emissions were obtained at higher speed with all biodiesel fuels. The maximum reduction in smoke level was 29.47% with T60-12 at 1,800 rpm.

Ranaware A. A. et al. [16] had investigated the performance and emission characteristics of a compression ignition engine by correlating the cerium oxide nanoparticles and water-based ferrofluid as additive to diesel fuel. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or soak up the oxygen for the reduction of NOx. The activation energy of cerium oxide burn off carbon deposits within the engine cylinder wall and reduces the HC emissions. The ferrofluid was prepared on reacting iron II (FeCl2) and iron III (FeCl3) ions in an aqueous ammonia solution. All the results had represented against the break mean effective pressure. The experiments shown that highest brake thermal efficiency was obtained 25.66% for neat diesel whereas it was seen 23.63% for the D+CERIA25 blend under the same BMEP of 0.44MPa. On the other hand, 0.4% ferrofluid to diesel fuel improved the BTE by 3.33–6.89% relatively and adding 0.8% ferrofluid to diesel fuel increased the BTE by 5.33–12.17% relatively. The lowest BSFC was examined as 0.3586kg/kW-hr for the D+CERIA25 blend whereas it was 0.3931kg/kW-hr for neat diesel at the brake mean effective pressure (BMEP) of 0.44Mpa. It was found out that 0.4% ferrofluid added to diesel fuel decreased the BSFC relatively by 3.23–6.45%, and 0.8% ferrofluid added to diesel fuel decreased the BSFC relatively by 5.06–10.85%. Also, from the analysis of engine exhaust emissions, it was seen that NOx emissions were lower than that of diesel fuel of D+4F and D+8F at all loads. Adding 0.4% ferrofluid to diesel fuel reduced NOx emissions by 9 to 15 ppm, and adding 0.8% ferrofluid to diesel fuel cut NOx emissions by 14 to

24ppm. But the CO emissions were increased when used ferrofluid and in opposite case cerium oxide nanoparticle added fuel shown the decreasing trend for the CO.
The results of this paper had shown that If both cerium oxide nanoparticles & ferrofluid are added to the neat diesel then we can improve performance & emission characteristics of CI engines.

Samarjeet Bagri et al. [17] experimental work had done on single cylinder, water cooled, two stroke, direct injection, Textool Diesel Engine under the full load and varying speed at 300,500,700rpm using SC5D additive in different -different proportions. The blends were prepared D0 (pure diesel), D1 (1000:1) ml , D2 (1500:2)ml, D3 (2000:3)ml, D4 (2500:5)ml, D5 (3000:7)ml. The emissions and performance results were compared with base fuel diesel. By adding of this additive, it was found out that cetane index number was increased from 46.22 as of base fuel to 47.63, 49.40, 51.91, 54.91 and 60.66 respectively. The results revealed that HC, CO& NOX emissions were reduced by 35%, 30% & 4% respectively. Brake power was boosted 6% whereas brake specific fuel consumption and smoke density were reduced by 23% and 35%. It was seen that, when cetane index number was increased from 54.91 to 60.66 the engine performance and emission characteristics were not effective. The results revealed that the cetane index no. was increased from 46.22 to 54.91, brake power increased and brake specific fuel consumption reduced linearly in all speeds, 300, 500 and 700 rpm.

Lu Xing cai et al. [18] had determined the influence of cetane number improver on performance ,combustion characteristic, heat release rate and emissions of a high-speed DI ,water cooled four cylinder diesel engine fueled with diesel ,ethanol–diesel and different percentage of cetane number enhancer (0,0.2,0.4%) blend fuel . The analysis-grade anhydrous ethanol (99.7% purity) were mixed with solublizer 1.5%v/v and then blended with diesel. The results revealed that from the combustion analysis the ignition delay extended and the total combustion duration decreased for ethanol–diesel blend fuels when compared to diesel fuel. The combustion characteristics of ethanol–diesel blend at higher load may be nearest to diesel fuel by CN improver, but a large difference exists at lower load. From the heat release rate at specific BMEP at 3400 r/min, it was found that the premixed combustion for all ethanol–diesel blends was increased when compared to neat diesel fuel, but the premixed combustion gradually decreased with the increase of CN improver volume in blend fuels. It was seen that the BSFC and thermal efficiency improved remarkably when engine operated with CN improver. From the emission results it was found that CO increased at lower and medium load, while the increasing trend decreased at higher load with CN improver. The HC was very lower at all loads. The NOx and smoke emissions decreased at all loads simultaneously for all blends as compared to diesel.

V. Arul Mozhi Selvan et al. [19] evaluated the combustion, performance and emission characteristic of variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes which were mixed with the Diesterol each at the rate of 25 ppm, 50 ppm and 100 ppm. Castor oil biodiesel act as a bridging agent for Diesel and Ethanol those were immiscible in each other. Combustion, performance and emission results were taken at optimum compression of 19:1 but at different loading conditions. Results showed that, the Carbon Nanotubes decreases ignition delay and advances the peak heat release rate where as Cerium Oxide Nanoparticles donates oxygen which helps in the oxidation and reduction of carbon monoxide and nitrogen oxides respectively. Cerium Oxide also provides extra energy to burn off carbon deposits within the engine cylinder. Decrease in harmful exhaust gas emission and cleaner combustion was the significant effect of both.

T. Shaafi et al. [20] investigated the performance and emission characteristics of two blends diesel- soybean biodiesel blend(D80B20) and diesel-soybean biodiesel-ethanol blends with alumina additive 100 mg/l and 1% isopropanol (D80B15E4S1+alumina(100mg/l)) on naturally aspirated, air cooled , single cylinder constant speed compression ignition engine. Alumina nanoparticles were added to blends with the help of ultrasonicator. Results showed that higher cylinder pressure and heat release rate was observed for alumina added blends as compared to neat diesel. In case of alumina added blend brake thermal efficiency was obtained 17.9% increasement than neat diesel. It was seen that BSFC 11.46% declined and minimum BSEC for alumina added fuel as compared to diesel. Exhaust gas temperature also decreased in the case of alumina blend. Further, the soybean biodiesel provided extra oxygen and alumina nanoparticles accomplished complete combustion and resulted in decreased CO, CO_2 and UBHC. But NOx emission was observed 9.9 % higher than diesel.

K. Muralidharan et al. [21] studied the performance, combustion and emission characteristics of waste cooking oil methyl ester and its blends (20%, 40%, 60% and 80% by volume biodiesel) with diesel. Transesterification process was used for the production of biodiesel. All the experiments were performed on single cylinder four-stroke variable compression ratio engine at a constant speed of 1500 rpm and 50% load. Compression ratio was varied from 18:1 to 22:1. All the graphs were plotted against the different compression ratio. Maximum brake power of 2.07 KW was obtained for B40 at compression ratio of 21:1 on the other hand for diesel fuel it was 2.12 KW. Whereas brake thermal efficiency was slightly higher and specific fuel consumption was lower in case of B40 as compared to diesel. Exhaust gas temperature was higher than diesel for all blended fuels at lower compression ratios whereas it was lower than diesel in case of higher compression ratios. The hydrocarbon emission for B40 shown increasing trend with increase in compression ratio. NOx emission was observed for B40 higher than other blends and diesel. It was seen 6400 ppm and 621 ppm for B40 and diesel. The CO emissions were found nearest to diesel but at higher compression ratio observed higher. At lower compression ratio lesser CO_2 was seen but at higher compression ratio vice versa. At higher compression ratio biodiesel blends released higher combustion pressure.

Prabhu L et al. [22] reported the effect of titanium oxide nano particle on combustion and emission characteristics of single cylinder diesel engine. Titanium oxide nano particles were added to 20% biodiesel (Neem oil methyl esters) diesel blend with the concentration of 250 ppm and 500 ppm. Ultrasonication process was used to stabilize the nanofuels. The diameter of nanoparticles was varied between 1-100 nm size. B20 with 250 ppm nano particle showed 1.32% increasement in brake thermal efficiency as compared to B20 with 500 ppm at full load conditions. The carbon monoxide and hydrocarbon emission was reduced 20% and 17.5% with the blended fuels of 250 ppm as compared to 500 ppm concentration wit B20 and without addition of nanoparticles of B20. The NOx emission was increased up to 5% and smoke opacity declined 27% for B20 with 250 ppm added nanoparticles compared to B20 with 500 ppm and for B20 at full load conditions.

Mohammed EL_Kassaby et al. [23] examined the effect of compression ratio on engine fuelled with biodiesel. Biodiesel was produced from the waste cooking oil collected from the restaurants with the help of transesterification process and the mixed with pure diesel to produce blends with the concentration of 10%, 20%, 30% and 50% by volume. In the experiment compression ratio was varied from 16 to 18 with the step of two. Emission and combustion data obtained from the experiment shown that, with the increases of compression ratio engine torque was increased for all the blended fuels as compared to pure diesel. Brake thermal efficiency was increased by 18.39%, 27.48%, 18.5% and 19.82% for B10, B20, B30 and B50 respectively. From the emission point of view blends shown nearly 52% and 37.5% reduction in HC emission and CO emission when compression ratio varied from 14 to 18. CO_2 and NO_x emission was increased by 14.28% and 36.84% respectively when compression ratio changed from 14 to 18. It was concluded that delay period was decreased 13.95% during the variation of compression ratio from 14 to 18.

J. Sadhik Basha et al. [24] conducted an experiment on single cylinder constant speed diesel engine to study the effects of Carbon Nanotubes (CNT) which were added 25,50 and 100 ppm concentration to Jatropha Methyl Esters (JME) emulsion fuel. Transesterification process was used to produce Jatropha Methyl Esters from the Jatropha oil and then 5% water with 2% surfactant by volume was added to produce JME emulsion fuel. The HLB (hydrophilic-lipophilic) value was 10. The stability of CNT added emulsion fuel was more than five days due to high speed agitation at 3000 rpm. Experimental results revealed that, 100CNT blended JME emulsion fuel shown 28.45%, JME emulsion fuel shown 26.34% and neat JME shown 24.80% increase in brake thermal efficiency at full load. The reduction in peak cylinder pressure was observed when added 100 ppm concentration of CNT to the JME emulsion. Further, the harmful emission gasses like CO, NOx and smoke reduced due micro-explosion and secondary atomization phenomena's. There was nearly 31% reduction in NOx emission with neat JME and 51% reduction for CNT blended JME emulsion fuel.

Mohamed F. Al-Dawody et al. [25] performed the experiment on single cylinder, direct injection variable compression diesel engine fuelled with soybean methyl ester (SME) blend with diesel to study the effect of compression ratio on performance combustion and emissions. The experiment was conducted at compression ratios of

15, 16, 17.5 and 19 while speed remained constant 1500 rpm. Three blends was prepared by adding soybean biodiesel to diesel with a concentration of 20%, 40% and 100% on volume basis and named as B20, B40, and B100. As Increased the concentration of biodiesel decreased the heat release rate. Hydrocarbon, carbon monoxide and smoke from engine decreased when increased the compression ratio from 15 to 19. The NOx emission was increased when compression ratio varied from 15 to 19. From all the above three, B20 was given best results as compared to B40, B100.

C. Syed Aalam et al. [26] studied the effect of 25 % zizipus jujube methyl ester blended with diesel fuel on performance, combustion and exhaust emissions characteristics in single cylinder, common rail direct injection (CRDI) system supported diesel engine. Aluminum oxide nanoparticles were also added with a concentration of 25 ppm and 50 ppm on mass basis, to blends with the help of a mechanical Homogenizer and an ultrasonicator. All the graphs were drawn against brake power. Blends with aluminum oxide nanoparticles shown a significant reduction in BSFC and exhaust emission. The HC and smoke emissions reduced from 13.459 g/kWh and 79 HSU to 8.599 g/kWh and 49 HSU with the addition of aluminum oxide nanoparticles. Nanoparticles also had shown a dominant effect on brake thermal efficiency and heat release rate.

G. Vairamuthu et al. [27] explored the effect of Calophyllum Inophyllum biodiesel on performance, combustion and emission characteristics in single cylinder, vertical, naturally aspirated four stroke, water cooled, Direct injection, constant speed, Kirloskar diesel engine. Cerium oxide nanoparticles were added to diesel blends using ultrasonic agitator. Precipitation method was used for synthesis of cerium oxide nanoparticles. The concentration of cerium oxide nanoparticles was kept 20 ppm to the biodiesel blend. Brake thermal efficiency was seen as 25.09% for B100+200 ppm, whereas it was observed 21.61% for the B100 fuel. Cerium oxide nanoparticles were provided additional oxygen for the oxidation of carbon monoxide and reduction of nitrogen oxides. The NOx reduced up to 25.08% at full load while using nanoparticles.

Hwanam kim et al. [28] considered the blend of diesel (80%), biodiesel(15%) and ethanol(5%) called biofuel to evaluate the particle size distribution. The test was performed on common rail direct injection diesel engine (CRDI) powered with biofuel-blended diesel fuels. The CRDI engine equipped with warm-up catalytic converters (WCC) and performance and emissions were examined in an ECE (Economic Commission Europe) R49 test and a European stationary cycle (ESC) test. The engine performed under a biofuel-blended diesel fuel nearly to D100. The higher fuel consumption was observed when using biofuel. The use of a biodiesel–diesel blend fuel reduced the hydrocarbon and carbon monoxide emissions but increased (NOx) The biofuel shown that smoke emission was declined by 50%. The particle emission from the exhaust of the engine found less with biofuel whereas it was observed more with biodiesel blends. It was concluded that biofuel shown more interesting results for the decline of particle number as compared to biodiesel blend.

GVNSR Ratnakara et al. [29] performed the experiments on variable compression ratio single cylinder four stroke diesel engine. In this research experiments were conducted using diesel fuel to determine the optimum compression ratio. The compression ratio was varied on engine 13.2, 13.9, 14.8, 15.7, 16.9, 18.1 and 20.2. All the graphs were plotted against the brake power. Results showed that compression ratio 14.8 was shown less fuel consumption, less smoke emission and moderate temperature of exhaust.

Mehardad Mirzajanzadeh et al. [30] investigated the performance and emission characteristics of novel –soluble additives biodiesel OM355 EU2 engine at IDEM Company. All the experiments were performed at 1000, 1200, 1400, 1500, 1600, 1800, 2000 and 2200 rpm at full load. At 1500 rpm lends produced maximum torque. Novel –soluble additives were hybridized of cerium oxide and multiwall carbon nano tubes using solvent –aided method. After the hybridization size of the nanoparticles 40-50 nm was confirmed by SEM. Two biodiesel blends B5 and B20 was prepared with diesel and 30, 60, and 90 ppm concentrations were added to the blends. All the result was graphed against the different fuel blends at 1500 rpm and full load. Results showed that power and torque was improved by 7.81% and 4.91% respectively for the B20 with 90 ppm concentration when compared to B20. The fuel consumption was decreased up to 4.50% for the B20 with 90 ppm blend compared to B20. CO, NOx, soot and HC were reduced by up to 38.8%, 18.9%, 71.4% and 26.3% in B20 with 90 ppm as compared to pure B20.

Hani Chotai et al. [31] reviewed the performance and emission characteristics of biodiesel blends on variable compression ratio diesel engine. Also the effect of injection pressure and injection timing was studied. In this paper effect of compression ratio on BSFC, BTE, CO, smoke emission and exhaust gas temperature was presented. Results showed that BSFC was higher at lower and higher compression ratio due to incomplete combustion and charge dilution. It was concluded that brake thermal efficiency increased as the load increased on the engine due to the better combustion and less losses. Review concluded for smoke emission that it was increased at both lower and higher compression due to the incomplete combustion at lower compression ratio and more fuel consumption at higher compression ratio. Exhaust gas temperature was increased with increase in compression ratio.

K. Srinivasa Rao et al. [32] analyzed the performance and emission characteristics of diesel and diesel–biodiesel blends on single cylinder four stroke compression ignition diesel engine using cerium oxide nanoparticles. The cerium oxide nanoparticles were added to the pure diesel and B20 (20% biodiesel by volume). The nanoparticles were mixed in the proportion of 20, 40 and 60 ppm to the B20. The biodiesel was prepared by transesterification process from eucalyptus oil. Using high speed ultrasonication stability was improved. Results were plotted against the load. It was observed that BTE was shown improving trend with all the nanofuels from B20. The least BSFC was reported 0.268 kg/kW-hr for B20 with 60 ppm addition of nanoparticles at full load. Results showed that cerium oxide was acted as oxygen buffer and results reduced the both CO and NOx. Results revealed that the activation energy of cerium oxide nanoparticles helped to reduce the HC emissions.

Ganesh et al. [33] had performed the experiments on single cylinder four stroke diesel engine at 1500 rpm to study the performance and emission characteristics. The nanofuels additive Cobalt Oxide (Co3O4) and Magnalium (Al-Mg) were added 100 mg/l to the B100 jatropha biodiesel. Synthesis of Cobalt Oxide was done with Sol-Gel method and Magnalium with Ball Mill method. The range of particle size was characterized with SEM and size varied between 38-70 nm. The cationic surfactant Cetyl Trimethyl Ammonium was used to stabilize the nanofluid. Surfactant was added 100% wt. of the nanoparticles to the nanofluid. All the results were plotted against the BMEP. Nearly 1% enhancement was seen in BTE for magnalium added biodiesel as compare to pure biodiesel. At 75% load on the engine cobalt oxide added biodiesel shown 83% decline in HC compare to pure biodiesel. A same trend was seen with magnalium additive and at 50% load 70% decline observed of HC. On the addition of magnalium the CO reduction was observed about 66% at 50% load conditions. The similar trend was followed by cobalt oxide and shown 50% reduction at 75% load. The drastic results were seen with NOx when added cobalt oxide. About 47% reduction was seen with these nanofuels. Cobalt oxide showed better decrease in NOx at all load compare to magnalium.

Basha et al. [34] experiments were performed on single cylinder four stroke compression ignition diesel engines at 1500 RPM with an electrical loading apparatus. Carbon Nanotubes (CNT) nanoparticles were dispersed to the neat diesel to improve the performance and emissions. Electric arc discharge process was used to synthesize the nanoparticles. The CNT concentration was varied by mass fraction in the proportions of 0.5 g/lit, 1 g/lit, 1.5 g/lit. All the results were shown against BMEP. The BTE and BSFC were seen to be advanced with CNT blends. It was seen that level of emissions such as CO, NOx, HC, EGT and smoke was reasonably less compared to pure diesel.

Ajay Kumar et al. [35] had reported in this publication that water /diesel emulsion decrease the emissions without compromising with performance characteristics. The commercial diesel had reported rise in emissions. To overcome the problem next generation fuel nanofluid was studied. Nanofluid had shown the potential to reduction in emissions and improvement in performance characteristics. The combustion efficiency, fuel properties and ignition delay were improved using nanoparticles. A surfactant was reported that it was enhanced the stability of nanofluid. Authors had reported that cerium oxide nanoparticles can used with water /diesel emulsion to improve the performance and emission characteristic on four cylinder four stroke diesel engine. The effect of various dose levels can also be studied.

Gurinder Singh et al. [36] reviewed the literature to study the performance and emission characteristics of CI engine using biodiesel with additives as alternative fuel. Biodiesel had not shown significantly improvement in performance, but shown decreasing trend in emission parameters, especially in Sox, CO and CO_2 except to NOx. Nanoparticle added fuel improves the emissions and performance of CI engine due to the positive effect of nanofuels on the fuel properties and ignition delay. To improve the performance and emission especially NOx and particulate matter of diesel and diesel blended with biodiesel nanofuels had become an essential part of today's fuels. From the literature concluded that addition of nanoparticles in diesel and diesel-biodiesel blends not only enhanced the calorific values but also promotes complete combustion due to higher evaporation rates, reduced ignition delay, higher flame temperatures and prolonged flame sustenance. Nanometal oxide additives were reported to be effective in lowering diesel emissions.

Yu Ma et al. [37] had accounted the results of experiments perform on single cylinder four stroke diesel engine. The Fe-based combustion promoter homogenous catalyst contained ferrous picrate was mixed in the pure diesel in the ratio of 1:3200 (FTC-D) and investigations 1:10000 (FPC-D). Test was performed at 2800 rpm and 3200 rpm engine speed respectively. The results were plotted against the BMEP. After the addition of very low dosage of FTC and FPC fuel properties were not changed. Results concluded that maximum 3.7% BSFC decreased at 3200 rpm and 0.14 MPa BMEP for FTC-D than reference diesel. On the other hand FPC-D shown 3.1% BSFC reduction at 2800 rpm and 0.14 MPa BMEP compared to reference diesel. In the case of emissions of CO, Particulate matter and UHC using picrate solution maximum reduction were observed 21.1%, 39.5% and 13.1%. But in opposite for NOx emissions had not shown any positive effective. Due to the improved fuel combustion efficiency a little higher NOx observed.

S. Krthikeyan et al. [38] conducted the experiment on single cylinder four stroke vertical diesel engines at 1500 rpm constant speed. The compression ratio and injection timing was set 17:1 and 23.4^o bTDC for all the tests. The grape seed oil methyl ester biodiesel prepared by transesterification method and blends were prepared by emulsification technique. The cerium oxide nanoparticles were dispersed to the B20 (20% biodiesel and 80% diesel) in the concentration of 50 ppm and 100 ppm. The stability of nanoparticle s added blends were extended using mechanical agitator and ultrasonicator. The average particle size was obtained 100 nm. All the graphs were made against the brake mean effective pressure. The fuel properties were improved. The results revealed that performance characteristics Brake thermal efficiency BSFC were improved due to the addition of cerium oxide nanoparticles to the blends compared to the biodiesel blend without nanoparticles. This was happened due to the complete combustion. The similar trend was observed with CO, NOx and HC. More the concentration more the reduction in emissions was observed due to higher surface area to volume ratio and better A/F ratio.

S. Krthikeyan et al. [39] performed the experiment on single cylinder four stroke vertical diesel engines at 1500 rpm constant speed. The compression ratio and injection timing was set 17:1 and 23.4^o bTDC for all the tests. The grape seed oil methyl ester biodiesel prepared by transesterification method and blends were prepared by emulsification technique. The zinc oxide nanoparticles were dispersed to the B20 (20% biodiesel and 80% diesel) in the concentration of 50 ppm and 100 ppm. The stability of nanoparticle s added blends were extended using mechanical agitator and ultrasonicator. The average particle size was obtained 100 nm. All the graphs were made against the brake mean effective pressure. The fuel properties especially improved and it were effected the BTE and BSFC. The results revealed that performance characteristics Brake power, Brake thermal efficiency and BSFC were improved due to the addition of zinc oxide nanoparticles to the blends compared to the biodiesel blend without addition of nanoparticles. The exhaust gas temperature was seen slightly higher the biodiesel blend B20. This was happened due to the complete combustion. The similar trend was observed with CO, smoke and HC. More the concentration more the reduction in emissions was observed due to higher surface area to volume ratio and better A/F ratio. But higher NOx and CO_2 was observed for nanoparticles added fuel compared to B20.

Hojjat Ahmad et al. [40] studied the effect on the on the engine oil properties of copper oxide nanoparticles as a additives. The thermal conductivity, flash point pour point and viscosity were measured. The nanoparticles were added to the engine oil in the concentration of 0.1, 0.2 and 0.5 wt. % the size of the nanoparticles were less than

100 nm and confirmed with SEM. The nanoparticles were dispersed to the lubricant using ultrasonic, bath and planetary ball mill. The thermal conductivity and flash point was improved 3% and 7.5% adding 0.1 wt% nanoparticles with respect to base fuel. Pour point was improved by 3.7% with the concentration of 0.2 wt. % compared to base oil. It was concluded that 2.0 wt. % shown optimum blend because at this concentration flash point was improved without compromising with viscosity.

Yanan Gan et al. [41] investigated the combustion characteristic, loading rate particle materials of nanofluid. The nanofluid was prepared with the addition of boron and iron particles to n-decane and ethanol fuel. The dense and dilute suspensions were evaluated and dense suspensions revealed that some boron particles were burned simultaneously the base fuel and some made was agglomerated. The burning of these particles was depending upon the base fluid. The similar trend was seen with iron particles but agglomerated particles were able to burn with both the base fuel. During the dilute suspension without the surfactant addition to the ethanol base fuel particles were burned in the flame zone. The particles were continuously escaping from the droplet zone and reaching to the flame zone.

S. Kent Hoekman et al. [42] had reviewed the effect of biodiesel on NOx formation in four stroke compression ignition diesel engine. The results of different biodiesel blends were compared with base fuel diesel. The results revealed that generally biodiesel shown less emissions of HC, CO and particulate matter except the NOx. The results concluded that no single factor was responsible to increase the NOx. Many factor were responsible like radiative heat loss, injection timing, residence time, flame temperature exhaust gas temperature etc. the exhaust gas circulation and retardation of injection timing can be effected to reduce the NOx. The injection timing was advanced due to the higher compressibility factor of bulk modulus. On more factor higher oxygen content in biodiesel was increased NOx emissions. Two NAC (NOx absorber catalyst) or SCR (selective catalytic reduction) after treatment techniques was adopted to decrease the NOx emissions.

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CHAPTER 3

RESEARCH GAP AND OBJECTIVE

The increasing demands and scarcity of the petroleum products day by day leads to exploration of renewable energy resources. Owing to the biodegradable, better emission characteristics, superior lubricity and less toxicity biodiesel is a favorable alternative fuel. But due to the higher manufacturing cost of biodiesel from vegetable oil as well as feed stock waste mustard oil is a good alternative fuel because it is easily available from any fast food shop and restaurant etc. Another benefit of its lower manufacturing cost. Researchers and scientists are doing continuously efforts to improve performance and emission characteristics of biodiesel as a fuel in diesel engine. Now due to the advent of nanotechnology mixing of nanoparticle with biodiesel blends there is a better scope to improve the performance, combustion and emission characteristics of diesel engine.

3.1 Gap in research

There has been lot of research done so far on biodiesel production method, to improve the yield and performance and emission characteristics analyses of CI engine by varying the biodiesel proportions in diesel at different loads, speed and compression ratios. But its lower performance and higher emissions especially NOx is topic of interest for all the researchers. Now due to the advent of nanotechnology many researchers examined its effect on the fuel properties, engine performance and emission characteristics. A lot of work is being done using diesel as a base fuel and nanoparticle as an additive, by varying the dose level over CI engine. But limited study has been done using cerium oxide as a nanoparticle with diesel but no one have done research using cerium oxide nanoparticles as a additive/catalyst with diesel and biodiesel blends with variable compression ratio on CI engine.

3.2 Objectives of research

The literature surveyed has been carefully analyzed to find out the objective of the present study. The literature survey has studied on the basis of the performance and emission characteristics of diesel biodiesel blends on CI engine. The main objective of present investigation will be to do a comparative study on effect of cerium oxide nanoparticle dose level of 50 PPM in diesel-biodiesel fuel based on their performance and emission characteristics on variable compression ratio diesel engine. Two kind of biodiesel blend (B10 and B15) will be prepared using dose level of 50 PPM and it will be tested and examined at different engine load and repeated with 14, 16 and 18 compression ratios.

The objectives of the work will be carried out in following steps:-

1. Production of biodiesel from waste mustard oil using Transesterification process.
2. Determination of biodiesel properties.
3. Blending of nanoparticles with diesel and biodiesel blend.
4. Evaluation of performance parameters.
5. Evaluation emission parameters.
6. Comparison of performance and emission characteristics of diesel-biodiesel blends with nanoparticle added blends and base fuel diesel.

CHAPTER 4

METHODOLOGY

In this chapter the methodology for the preparation of biodiesel from waste mustard oil and procedure for the production of nanoparticle blended biodiesel is discussed. This chapter describes the process for the determination of different fuel properties of diesel-biodiesel blend and nanoparticle blended diesel-biodiesel samples from the four dissimilar blends (B10, B10$CeO_2$50, B15, and B15$CeO_2$50). These four blends were tested in a variable compression ignition diesel engine at different loads and compression ratios. The performance and emission variables such as brake power, brake thermal efficiency, fuel consumption, brake specific fuel consumption, exhaust gas temperature, CO, NOx and HC were investigated. These performance and emission parameters of all biodiesel blends were compared to those of neat diesel.

4.1 Methodology to be adopted

The work performed can be divided into following steps:-

1. Production of biodiesel using Transesterification process.
2. Evaluation of fuel properties.
3. Preparation of biodiesel blend.
4. Production of nanoparticles added biodiesel blends
5. Evaluation of Performance and Emission characteristics of biodiesel blends on variable compression engine.
6. Comparison of performance and emission characteristics of biodiesel with that of pure diesel

4.1.1 Production of biodiesel using transesterification process

Biodiesel was prepared from waste mustard oil using transesterification process. In this work, biodiesel was prepared with single stage transesterification process. Waste mustard oil can be arranged very easily from any restaurant, pakorawalas and sweet shops in our nation. The production of biodiesel was accomplished in the laboratory at Mechanical Engineering Research and Development Organization (MERADO) Ludhiana, Punjab (India) using materials like potassium hydroxide (KOH), methanol.

Various steps adopted in preparation of biodiesel from waste mustard oil are discussed as below:

- First of all the required waste mustard oil was taken in a conical flask and preheated to 60^0C for 60 minutes in water bath.
- Optimum percentage of methanol (by volume) 6:1 molar ratio and KOH (by weight) 1.5% was mixed and stirred in a separate conical flask.
- Then stirred sample was added in the waste mustard oil sample and again mixed properly by stirring.
- After that above sample was maintained at 60^oC for 60 minutes at constant stirring speed in water bath shaker.
- Then this stirred sample put into the separating funnel and left for 24 hours to remove the glycerol from methyl ester. After 24 hours the glycerol was removed and separated to obtain the methyl ester.
- Now the methyl ester was washed and boiled to remove the excess methanol, KOH, and other impurities and maximum yield 96.2% was obtained.
- Biodiesel ready to use into the CI engine.

Figure 4.1: Biodiesel prepared from waste mustard oil

4.1.2 Evaluation of fuel properties of biodiesel

The following properties of biodiesel were determined:

- Kinematic viscosity
- Calorific value
- Flash point
- Density

4.1.2.1 Apparatus used for evaluation of properties

The following apparatus were employed for the evaluation of biodiesel properties.

The Brookfield Viscometer: Brookfield Viscometer was used to determine the viscosity of nanofluid. The equipment consists of a spindle, small adaptor, a water jacket and a cylindrical sample holder. The sample of nanofluid is put into the sample holder and immersed spindle of the viscometer run into the sample holder. Then spindle determine the drag when it rotates into the sample holder. The CPE-42 spindle is used. The capacity of sample holder is 1 ml and temperature of the nanofluid is observed by the temperature sensor which can hold a small sample of volume 1 mL and the temperature of the test sample is monitored by a temperature sensor fixed into the water bath.

Figure 4.2: Brookfield Viscometer

Bomb calorimeter: Figure 4.3 shows the bomb calorimeter used for determining the calorific value of biodiesel The gross calorific value of the fuel samples was determined as per the IS:1350(PII),1970 by bomb calorimeter. A 1 ml fuel sample is burned in the bomb of calorimeter in the presence of pure oxygen. The sample is ignited electrically. After the ignition takes place in the bomb heat produced and rise in temperature is observed. Each sample is replicated three times. The gross heat of combustion of the fuel samples was calculated using the equation given below:

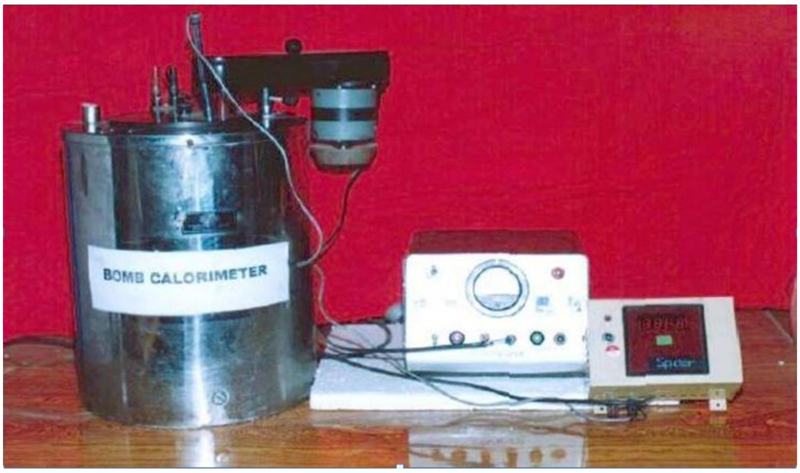

Figure 4.3: Bomb Calorimeter

$Hc = (Wc * \Delta T)/Ms$ …(1)

Hc = Heat of combustion of the fuel sample, Cal/g

Wc = Water equivalent of the calorimeter, Cal/^{o}C

ΔT = Rise in temperature, ^{o}C

Ms = Mass of sample burnt

Pensky Martin (closed cup) apparatus: The flash point is a minimum temperature at which, on introducing the test flame into the oil cup a distinct flash was observed. The fire point is a temperature of a oil at which the sample starts to fire continuously for minimum of 5 seconds.

Figure 4.4: Pensky Martin (closed cup) apparatus

The flash point of the fuel samples were evaluated as per IS: 1448 and is shown in figure 4.4. The oil cup is used to collect the sample of oil. The mark point on the oil cup is used to measure the sample. The oil cup is heated to increase the temperature 5 to 6 ^{o}C when the stirrer is revolved at approximately 60 RPM. The temperature is determined with the help of a thermometer of -10 to 400 ^{O} C range. At every 1 ^{O}C range, flame is introduced for a moment with the help of a shutter.

4.1.3 Preparation of biodiesel blend

Biodiesel blend was prepared with pure diesel by volume. Two different blends B10, B15 of biodiesel were prepared.

4.1.4 Production of nanoparticle added biodiesel blend

Cerium oxide nanoparticle was procured from XINYU ADVANCED MATERIALS LIMITED, CHINA. It was chosen to investigate its effect on diesel-biodiesel blend. To increase the stability and for proper mixing of nanoparticles in the biodiesel blend both ultrasonicator and mechanical agitator were used. The following steps were used in preparation of nanoparticle blended biodiesel:

- Magnetic stirrer was used to mix the cerium oxide nanoparticle (50 PPM/l). The suitable surfactant Cetyl Trimethyl Ammonium Bromide (CTAB) added by 100%wt of 50 PPM in biodiesel at a constant speed of 2500 r.p.m for 30 min in the first step. Cetyl Trimethyl Ammonium Bromide is a cationic surfactant and it forms an envelope on the surface of the particle and makes the surface as a negative charge.

- Then ultrasonication process was used to disperse the cerium oxide nanoparticle in the earlier mixture of biodiesel for 90 minutes.
- After that mechanical agitator was used to mix the neat diesel (90% by vol.) and biodiesel mixture of nanoparticles (10% by vol.) at a constant speed of 2500 r.p.m for 15 minute.
- The resultant blend yield the cerium oxide nanoparticle blended diesel-biodiesel fuel (B10$CeO_2$50).
- The same procedure was used to prepare the B15$CeO_2$50 blend.

Figure 4.5: Sonication of nanoparticles added biodiesel

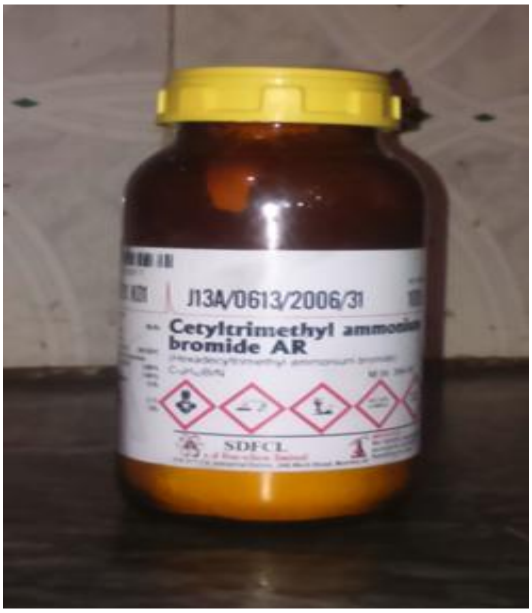

Figure 4.6: CTAB surfactant

Figure 4.7: Nanoparticle blended diesel-biodiesel blend

4.1.5 Evaluation of performance and emission characteristics of biodiesel

The prepared biodiesel blends for evaluation of engine performance and emissions were tested in internal combustion engine lab at Thapar University, Patiala.

4.1.5.1 Equipment used for the evaluation of engine performance

A four stroke, single cylinder variable compression ratio diesel engine was used for the present study. The performance and emission were evaluated on the variable compression ratio diesel engine using various blends of diesel and biodiesel as a fuel. The experiments were conducted at the constant speed of 1500rpm at various loads and compression ratios 14, 16 and 18. The compression ratio was varied by using tilting cylinder block without stopping the engine. The arrangement for measurement of airflow, fuel flow, temperatures and load provided. Air box, manometer, fuel tank, fuel measuring unit, transmitters for air and fuel flow measurements, engine indicator and process indicator has been assembled separately on panel box. The flow of cooling water and calorimeter was controlled with rotameter. Load cell sensor was used to vary the load on eddy current dynamometer which is coupled to the engine. Labview based Engine Performance Analysis software package "**Enginesoft**" is provided for on line performance evaluation. A variable compression ignition engine is described in figure 4.8.

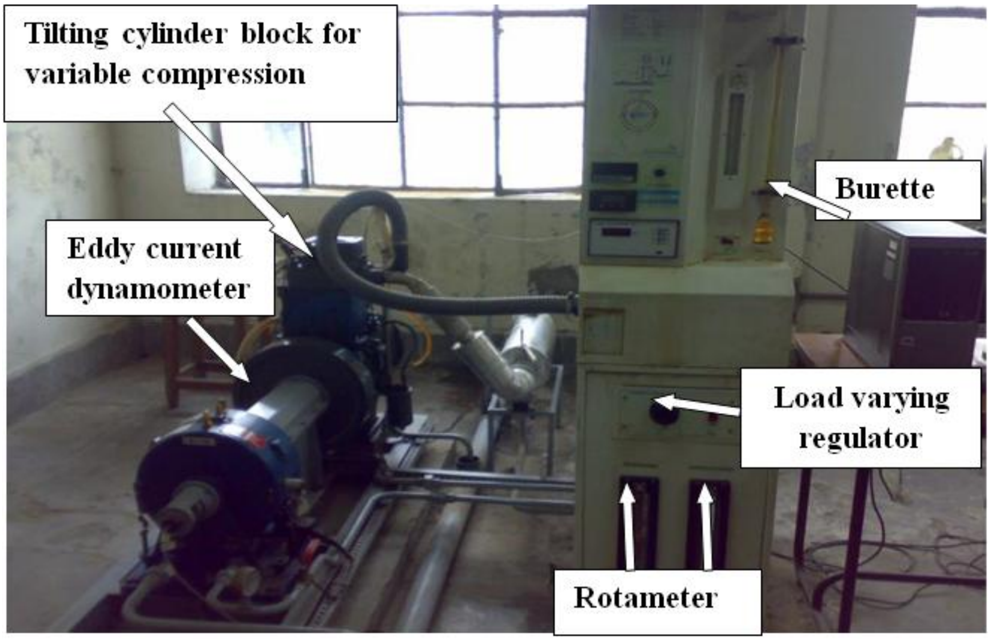

Figure 4.8: Single cylinder four stroke, variable compression ignition engine

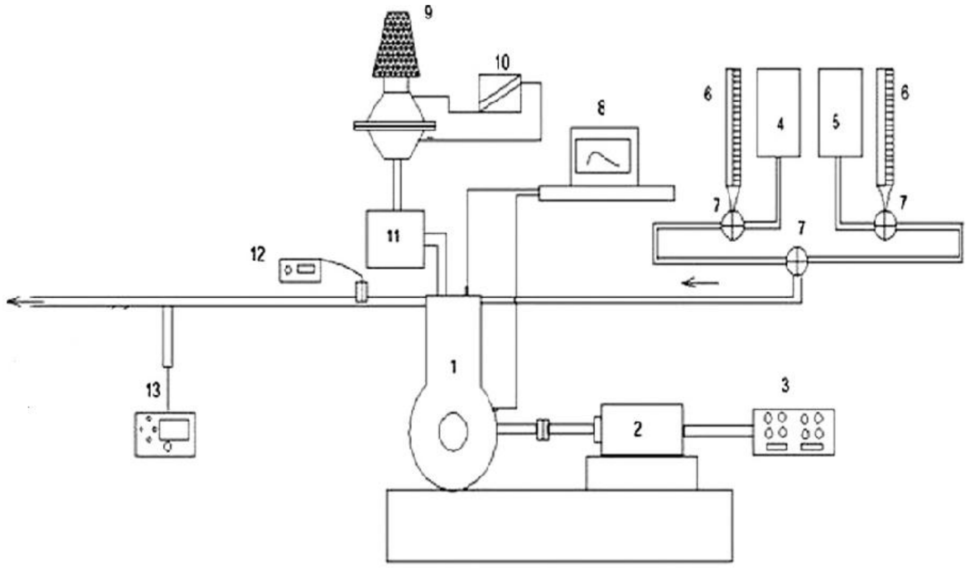

Figure 4.9: Schematic diagram of experimental system

1. Variable compression diesel engine
2. Alternator
3. Loading device
4. Biodiesel tank
5. Diesel tank
6. Burette
7. Fuel control valve
8. Data control system
9. Air filter
10. Manometer
11. Surge tank
12. Exhaust gas temperature sensor
13. Gas analyser

Specifications of the engine

The experiments were done on variable compression ignition engine. Specifications are as following:

Table 4.1: Specification of variable compression ignition engine

Engine Type	Single Cylinder 4-Stroke, Water Cooled diesel engine
Make Type	Kirloskar
Bore	87.5 mm
Stroke	110 mm
Connecting rod length	234 mm
Rated power	3.75 kW@1500 R.P.M
CR	Range from 12-18
Orifice diameter	20 mm
Dynamometer arm length	145 mm
Cooling media	Water cooled
Load indicator	Range 0-50 Kg, Supply 230V AC, Digital
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Loading device	Eddy current dynamometer
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Temperature sensor	Thermocouple, Type K
Speed indicator	Digital with non contact type speed sensor

Performance parameters evaluated

1. Brake Power
2. Brake thermal efficiency
3. Fuel consumption
4. Brake specific fuel consumption
5. Exhaust gas temperature

Experimental procedure

The following experimental procedure was followed on the engine for neat diesel and all the blend diesel-biodiesel blends with and without nanoparticles:

1. Fill the diesel and biodiesel both in respective fuel tanks.

2. In the starting, adjust the compression ratio of the engine to a ratio of 14:1.

3. After starting the water supply adjust the cooling water flow for calorimeter at 80 LPH and engine at 300 LPH and ensure the proper supply of water to piezo sensor for cooling and dynamometer cooling.

4. Before starting the electric-supply to the computer through the UPS check all the connections.

5. Click on the lab view based "**Enginesoft**" software package for on screen evaluation of performance.

6. Run the engine on diesel fuel for flashing.

8. Set the value of specific gravity and calorific value of the fuel in the software. Then select the run option and run the engine for 15 minutes under no load conditions.

9. Select log option in the software and assign the fuel supply by revolving the supply knob. Choose log option of the software. Before turn on the fuel supply knob, check that gas analyser is available there.

10. After 1 minute the display changes to input mode then enter the values of water flows in cooling jacket and calorimeter. Now enter the file name (applicable only for the first reading) in the software and insert the probe of gas analyser into the exhaust at appropriate place. Then it let for few minutes so that it could stabilize.

11. Logged the reading for no load conditions.

12. Repeat the experiment for different loads and compression ratios.

13. Save the readings for each load and compression ratio.

14. Repeat the experiment for particular fuel at different compression ratios.

15. At the end of the experiment bring the engine to no load condition and turn off the engine and computer.

16. After few minutes also turn off the water supply.

Precautions and Maintenance Instructions

1. Always make it sure before starting the engine that sufficient oil level is present in the oil tank.
2. Fuel tank and fuel line should not be contaminated.
3. Always ensure it that the supply of water is turned on before starting the engine.

4.1.5.2 Equipment used for the evaluation of engine emissions

For the evaluation of exhaust gas emission two equipments were used. Individual sensors attached to both the equipment. Horiba analyzer was used to determine the HC. Flue gas analyzer was used to evaluate the CO and NOx of the engine. Figure 4.10 and 4.11 shows the Horiba analyzer and Flue gas analyzer:

Figure 4.10: Horiba analyzer

Figure 4.11: Flue gas analyser

Emission parameters

Table 4.2 shows the emission parameters with their respective test methods.

Table 4.2: Exhaust emission parameters

Parameters	**Test method**	**Accuracy**	**Range**	**Resolution**
Carbon monoxide as CO(PPM)	Flue Gas Analyser(KM19106)	+/-20 PPM < 400 PPM 5% of reading <2000 PPM +/- 10% of reading > 2000 PPM	0–10000 PPM	1 PPM
Nitrogen oxides as NOx (PPM)	Flue Gas Analyser(KM19106)	+/- 5 PPM < 100 PPM +/- 5% of reading> 100 PPM	0–5000 PPM	1 PPM
Hydro Carbon as HC (PPM)	Horiba Analyser	---------	0-5000 PPM	---------

Experimental procedure

1. After starting the engine at no load conditions insert the probe of equipment into the exhaust of the engine.

2. Exhaust gases passes through these sensors to the respective analyzer attached with it.

3. After entering into the analyzer the readings were displayed on the digital screen.

4. After the 2-3 minutes when the values were stabilized 3 readings are noted down.

5. Mean value of the three readings was evaluated.

6. Sensors were removed for the values on the analyzers to settle down again to zero value.

7. Repeat the above procedure for different fuel and load condition respectively.

4.1.6 Comparison of performance and emission characteristics of biodiesel with that of pure diesel

After performing the experiments on variable compression engine, obtain data for all the four blends was used to compare the performance and emission characteristics with the characteristics of pure diesel.

CHAPTER 5

RESULTS AND DISCUSSIONS

In this chapter results have shown with the help of graphs and discussed the different reasons behind the results. The experiments were conducted on the variable compression ignition engine to evaluate the performance and emission characteristics of diesel and different blends of biodiesel with and without the addition of cerium oxide nanoparticles. Also the fuel properties were evaluated. The experimental results are discussed in the following steps:

Step I: The fuel properties of different biodiesel blendes with and without nanoparticles were compared with pure diesel.

Step II: Performance characteristics were described.

Step III: Emission characteristics were discussed.

5.1 Fuel properties

5.1.1 Kinematic viscosity

The variation of kinematic viscosity for different blends of biodiesel with and without cerium oxide nanoparticles were shown in figure 5.1.

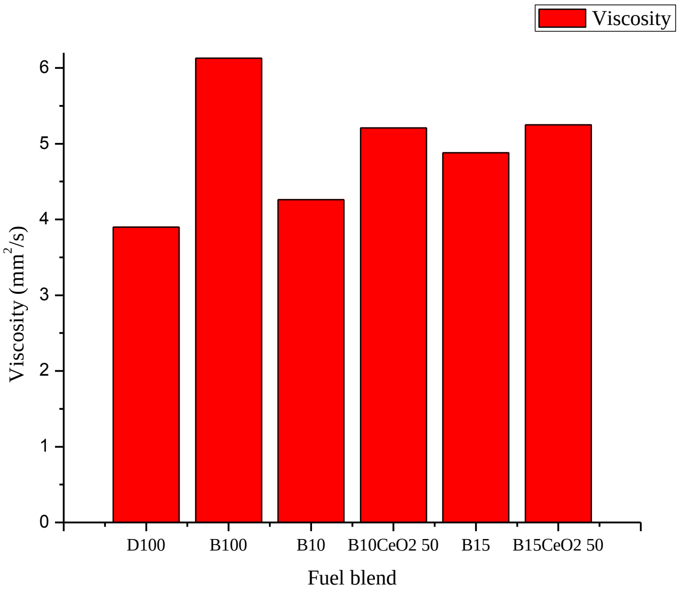

Figure 5.1: Variation of kinematic viscosity for different blends of biodiesel

It was seen that kinematic viscosity of biodiesel blend was further increased when dispersed 50 PPM concentration of nanoparticles. Maximum kinematic viscosity was observed for B15CeO$_2$50 blend. When dispersed nanoparticles to the fuel then it enhance the resistance between the fluid layer and results in increases the kinematic viscosity [1]. V. Sjith et al. also reported that viscosity was increased when added nanoparticles to the biodiesel [2]. The optimum fuel viscosity is desired because higher viscosity consumes more pumping power and promotes poor combustion. On the other hand lower viscosity generate leakage problem and more wear and tear takes place. The optimum kinematic viscosity should be compromise between both limits.

5.1.2 Flash point

The variation of flash point of different biodiesel blends with and without cerium oxide nanoparticles were described in figure 5.2.

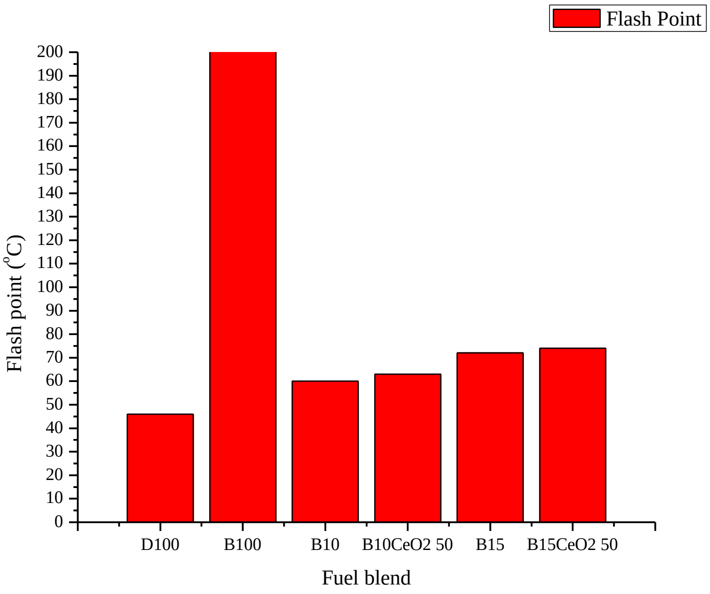

Figure 5.2: Variation of flash point of different blends of biodiesel

It was seen that flash point of biodiesel blend was observed to increase with the addition of nanoparticles. Ajin et al. reported that flash point was observed to increase when added nanoparticles to the fuel [2]. Flash point was increased due to the decrease in volatility of nanoparticles added fuel. One more reason is that when disperse nanoparticles to the fuel then increased its thermal conductivity which enhances the fuel resistance against ignition [3]. Higher flash point of liquid fuel is desirable for safe handling. For safe handling of liquid fuel always it should have high value

5.2 Performance characteristics

5.2.1 Brake power

5.2.1.1 Effect of blend and load on brake power

The variation of brake power with respect to load of different blends at compression ratio 14, 16 and 18 is illustrated in Figure 5.3, 5.4 and 5.5 respectively. Brake power of the engine increases as the load increases on the engine due to the more fuel burnt. It was observed that at no load and low load conditions, the brake power for pure diesel and biodiesel B10, B10CeO$_2$50, B15, and B15CeO$_2$50 is almost same. At higher and full load difference was observed for the all fuels but this was not significant. At higher load and compression ratio 14 biodiesel blend B10 generated more power than pure diesel but this difference was not significantly more. This is mainly due to complete combustion takes place inside the combustion chamber due to the excess oxygen in biodiesel. But biodiesel blend B15 was produced least power among the all blends due to lower calorific value, higher viscosity and density. To overcome the problem cerium oxide nanoparticles was added to the biodiesel blends. At higher and part load conditions cerium oxide nanoparticle added biodiesel blend B10CeO$_2$50 released maximum brake power among the all fuels. This is due to additions of nanoparticles which acts as oxygen buffer and promote complete combustion due to secondary atomization, to burn the hydrocarbons and derivatives on the cylinder wall, better mixing of fuel and air, long flame sustenance releases more energy [4, 5, 6]. Results at full load and all compression ratios are shown in table5.1.

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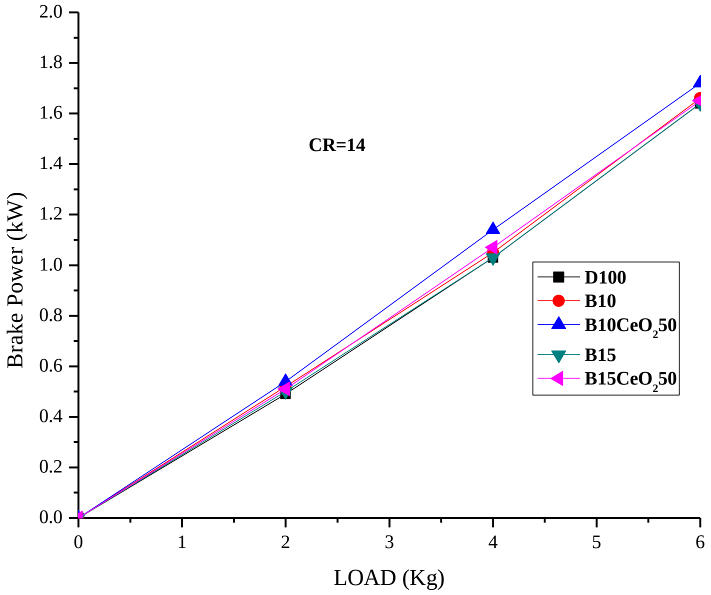

Figure 5.3: Variation of BP with respect to load at compression ratio 14

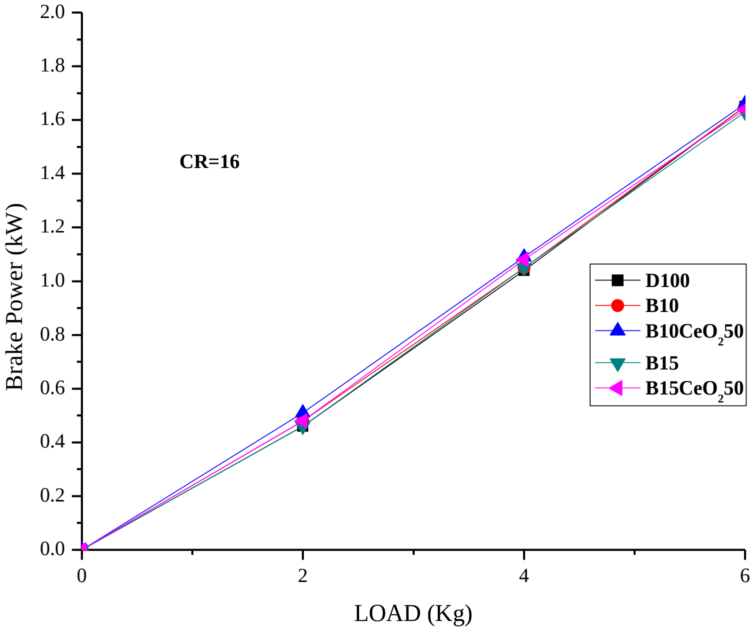

Figure 5.4: Variation of BP with respect to load at compression ratio 16

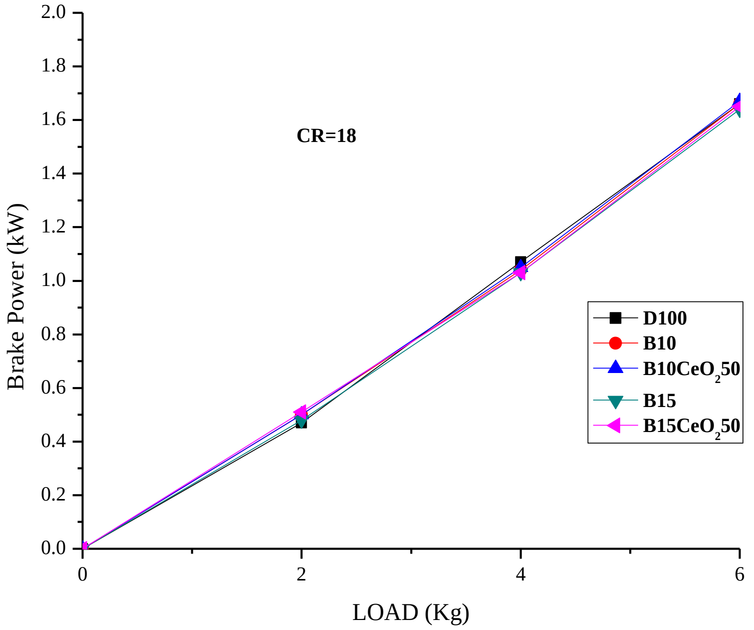

Figure 5.5: Variation of BP with respect to load at compression ratio 18

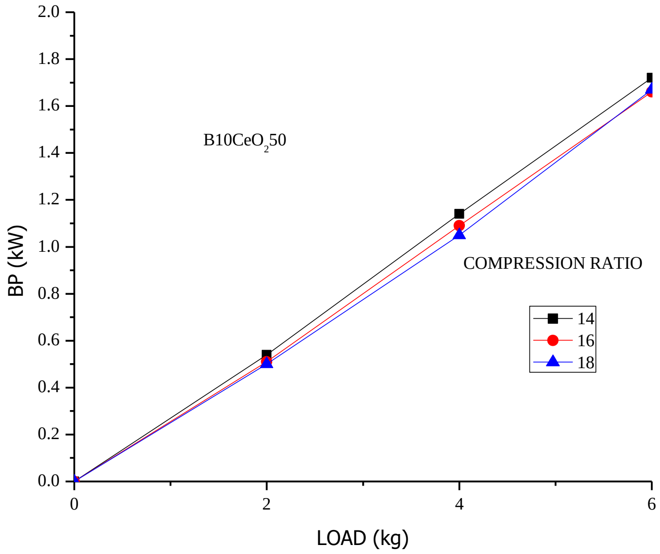

Figure 5.6: Variation of BP with respect to load of $B10CeO_2$ at compression ratio 14, 16 and 18

5.2.1.2 Effect of compression ratio on brake power

Variation of brake power at compression ratio 14, 16 and 18 with respect to load for optimum biodiesel blend B10$CeO_2$50 is shown in figure 5.6. It was observed that biodiesel blend B10$CeO_2$50 produced maximum power at full load and compression ratio 14. This is due to complete conversion from chemical to mechanical energy. At this compression ratio higher brake power can be attributed to better intermixing between fuel and air and better combustion [8]. Addition of nanoparticles help to remove the carbon deposit on the cylinder wall which results in reduces the frictional losses may be the reason for higher brake power [4].

Table 5.1: Brake Power at full load and CR 14, 16 and 18

Brake power (kW) at full load conditions			
CR	14	16	18
D100	1.64	1.65	1.66
B10	1.66	1.65	1.66
B10$CeO_2$50	1.72	1.66	1.67
B15	1.64	1.63	1.64
B15$CeO_2$50	1.65	1.64	1.65

5.2.2 Brake thermal efficiency

5.2.2.1Effect of blend and load brake thermal efficiency

The test were conducted for base fuel diesel and different blends of biodiesel B10, B10$CeO_2$50, B15, and B15$CeO_2$50 samples at different load and compression ratio 14, 16, and 18 as shown in figure 5.8, 5.9 and 5.10. It is well known that brake thermal efficiency is inversely proportional to BSFC.

It was observed that BTE was increased when the load was increased for all operations of diesel and blending fuel. The BTE was enhanced with the increase in load for the all fuels due to the less part of the power is vanished with increasing load. Also, BTE was found to decline with the increase in blend content of B10 and B15. This is due to the lower volatility, lower calorific value, higher viscosity, higher density and higher fuel consumption. The lower CV and ineffective utilization of thermal energy due to higher molecular weight of methyl ester, which combust completely on diffusion burning, late in the expansion stroke and results in BTE is lowest for neat biodiesel at all loading conditions [7].

To overcome the problem cerium oxide nanoparticle were blended with biodiesel samples B10Ce$O_2$50 and B15Ce$O_2$50 then it was observed that BTE improved among the all fuels as the load increases. This is due to the addition of nanoparticles to the diesel-biodiesel blend. The B10Ce$O_2$50 blend found to be higher BTE among the all fuels due to the cerium oxide nanoparticle encapsulation in biodiesel blend which offers the secondary atomization immediate after the primary micro explosion phenomenon of blending fuel as shown in figure 5.7. The presence of cerium oxide nanoparticles in the fuel promote complete combustion due to the releasing and storing capacity of oxygen led to increasement in BTE[1].

The various aspects like complete combustion owing to higher evaporation rates, reduced physical ignition delay, prolonged flame sustenance, better calorific value and higher flame temperatures of nanofuel leads to higher BTE [6]. To reduce the risk of agglomeration nanoparticles was coated with CTAB (Cetyl Trimethyl Ammonium Bromide) surfactant for stable atomization with nanoparticles so that constant BTE could obtained. Results of all the fuels at full load and all compression ratios are shown in table 5.2.

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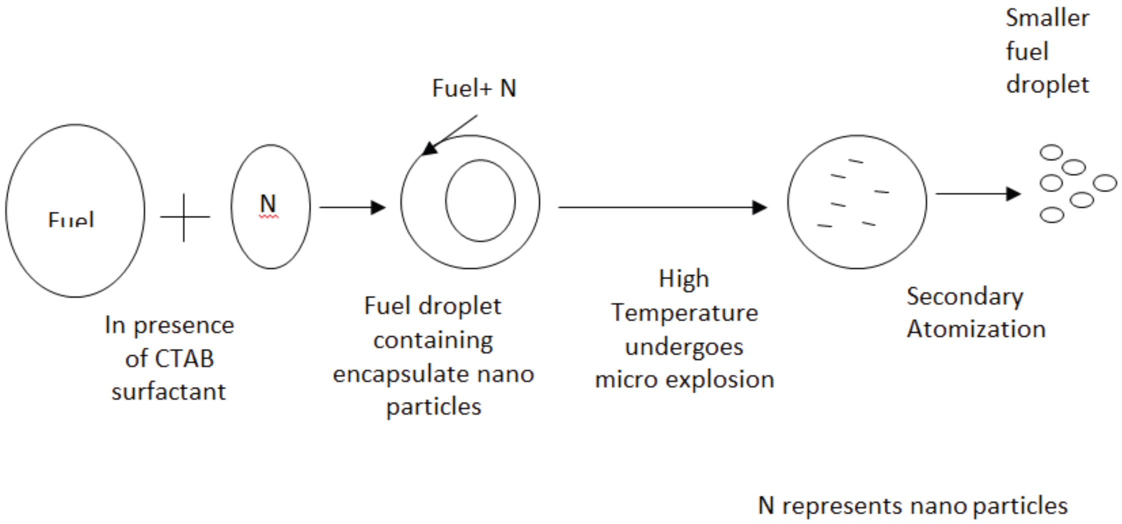

Figure 5.7: Microexplosion and secondary atomization of nanoparticles [7]

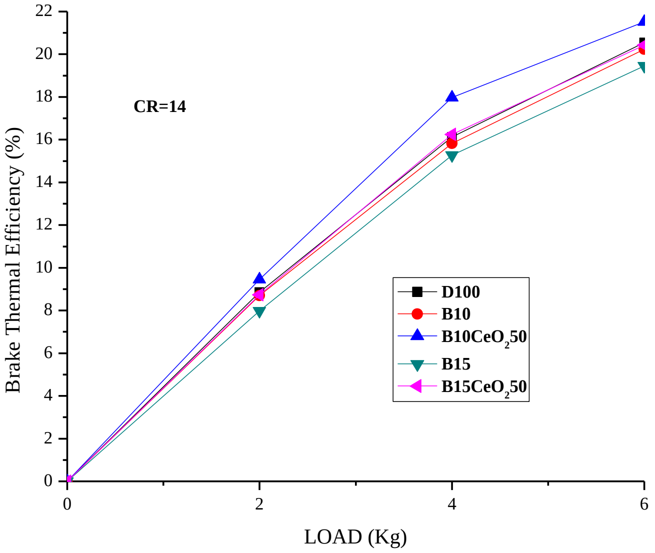

Figure 5.8: Variation of Brake thermal efficiency with respect to load at compression ratio 14

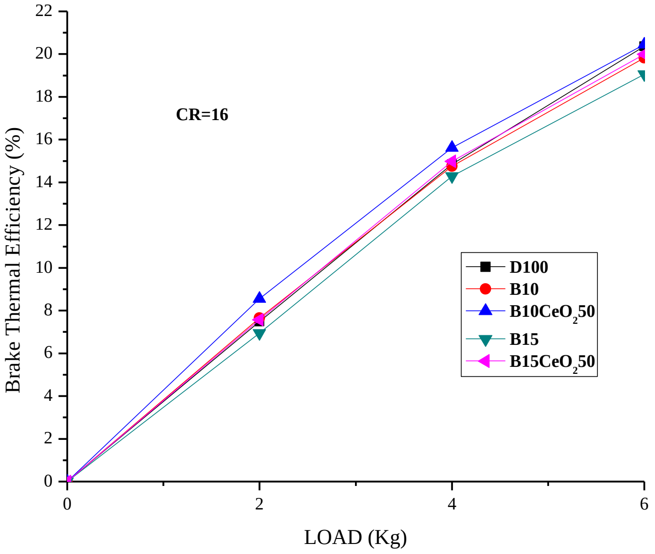

Figure 5.9: Variation of Brake thermal efficiency with respect to load at compression ratio 16

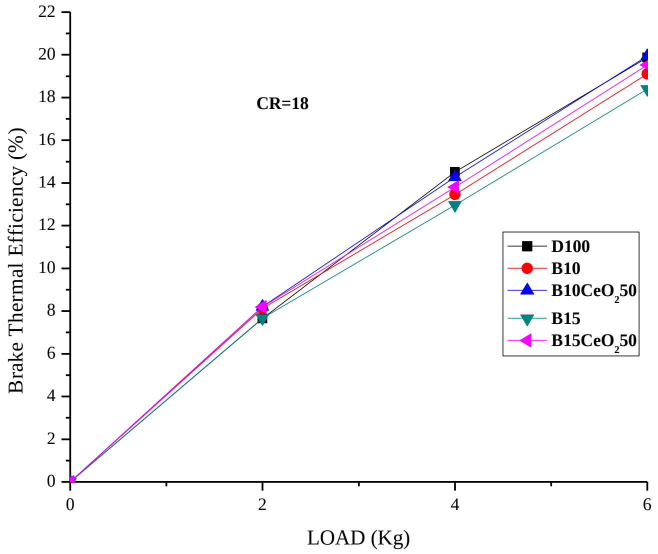

Figure 5.10: Variation of Brake thermal efficiency with respect to load at compression ratio 18

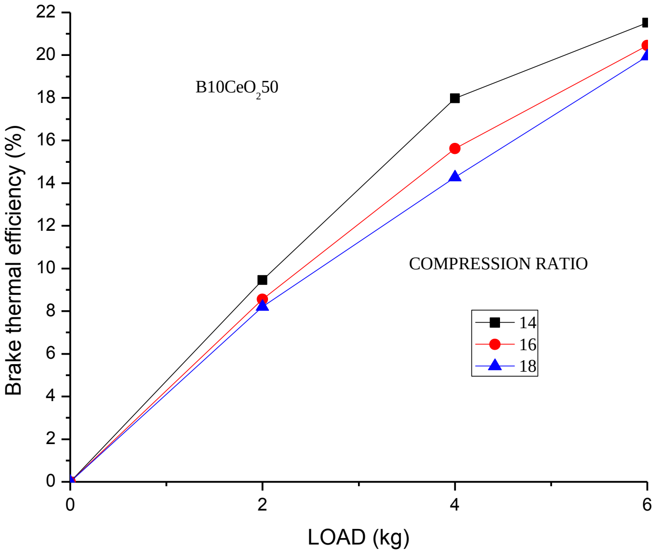

Figure 5.11: Variation of Brake thermal efficiency with respect to load of $B10CeO_250$ at compression ratio 14, 16 and 18

5.2.2.2 Effect of compression ratio on Brake thermal efficiency

Figure 5.11 shows the increasing trend for the entire compression ratio and maximum BTE was obtained at compression ratio of 14 of B10CeO$_2$50 which was 21.52%. The minimum BTE was 19.95% at compression ratio 18. Higher BTE at compression 14 could be attributed to the better combustion and better intermixing of the fuel with air [8]. One more reason was observed for the higher BTE was lower BSFC and better BP at compression ratio 14.

Table 5.2: Brake thermal efficiency at full load and CR 14, 16 and 18

Brake thermal efficiency (%) at full load conditions			
CR	14	16	18
D100	20.55	20.36	19.87
B10	20.23	19.82	19.1
B10CeO$_2$50	21.52	20.45	19.95
B15	19.45	19.06	18.4
B15CeO$_2$50	20.42	19.99	19.52

5.2.3 Fuel consumption

5.2.3.1Effect of blend and load on fuel consumption

The experiments were performed for neat diesel fuel and for different blends of biodiesel B10, B10CeO$_2$50, B15, B15CeO$_2$50 sample. The load on engine was varied from 0 to 6 kg at compression ratio 14, 16 and 18 and constant 1500 RPM. Experimentally, it was seen that the fuel consumption increases for diesel and biodiesel blends when the load was increased as shown in figure 5.12, 5.13 and 5.14. It was observed that B10 and B15 blend shown higher fuel consumption than that of other blends and conventional diesel at all loading conditions. This is due to the lower calorific value and higher viscosity of biodiesel blends compared to conventional diesel fuel [5].

Maximum fuel consumption was observed at full load operation. This is due to the greater amount of fuel energy is required to produce higher BP.

The cerium oxide nanoparticle blended fuel was shown lower fuel consumption as compare to other fuels. The cerium oxide nanoparticle blended biodiesel B10CeO$_2$50 and B15CeO$_2$50 were observed to be improving in fuel consumption. This is due to the increase in calorific value and provides excess oxygen for complete combustion due to addition of cerium oxide nanoparticle.

The cerium oxide nanoparticles put a stop to the formation of the carbon deposits which leads to decrease the frictional power of the cylinder and results in to reduce the fuel consumption [4]. By improving the combustion characteristics nanoparticles added blend making the CI engine to consume a lesser amount of fuel compared to other blend to prevail over the same load. B10CeO$_2$50 fuel was showed minimum fuel consumption among the all fuels at full load conditions due to the higher calorific value with greater combustion characteristics due to the good atomization and rapid mixing of fuel. Results of fuel consumption at full load and CR 14, 16, and 18 is shown in table 5.3.

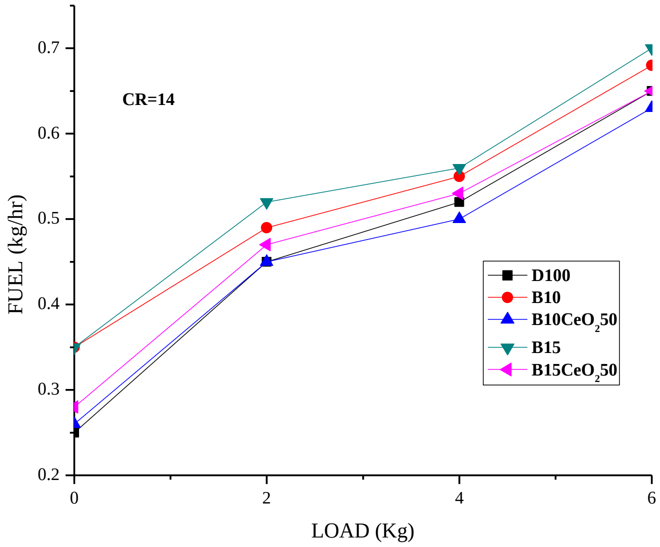

Figure 5.12: Variation of Fuel consumption with respect to load at compression ratio 14

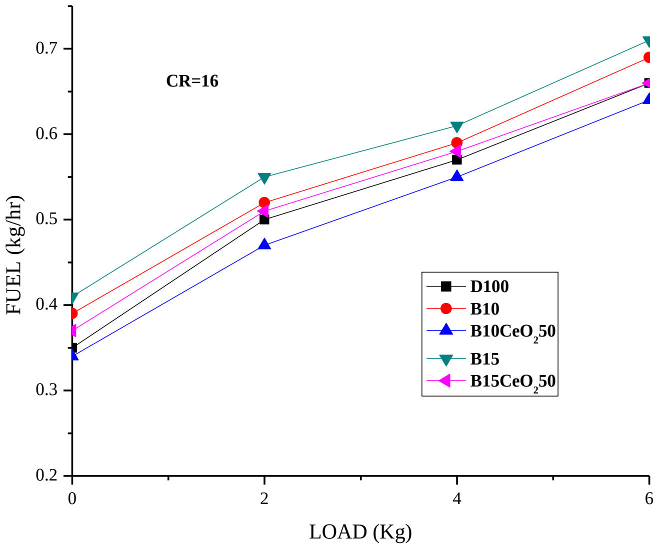

Figure 5.13: Variation of Fuel consumption with respect to load at compression ratio 16

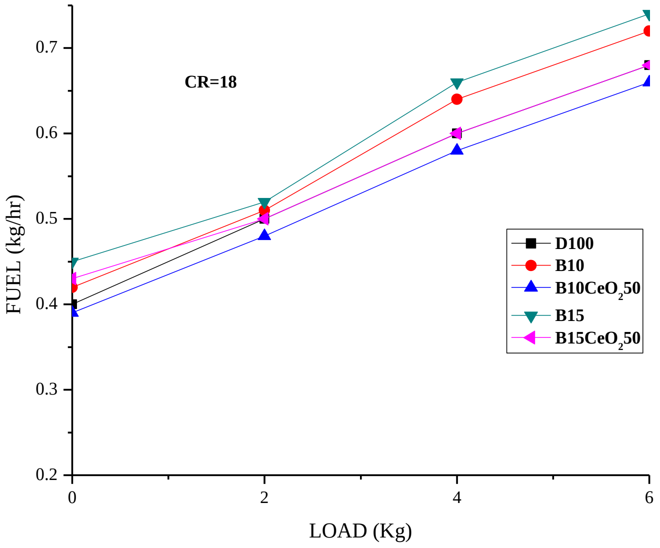

Figure 5.14: Variation of Fuel consumption with respect to load at compression ratio 18

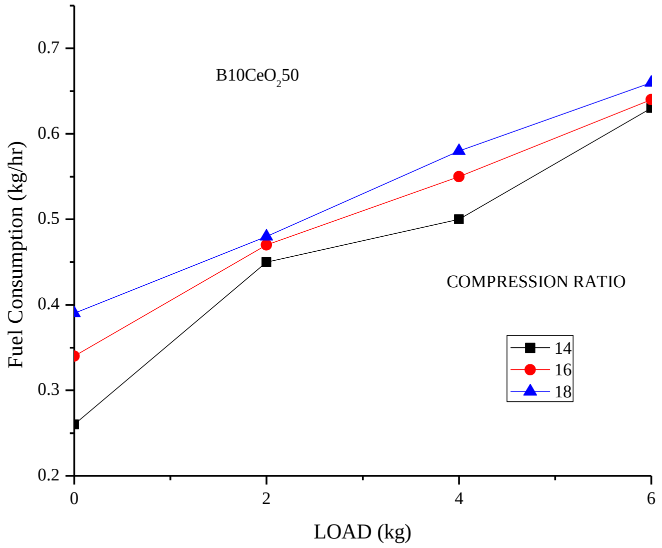

Figure 5.15: Variation of Fuel consumption with respect to load of B10CeO$_2$ at compression ratio 14, 16 and 18

5.2.3.2Effect of compression ratio on fuel consumption

The fuel consumption was observed to be increased with the increase in compression ratio from 14 to 18. The fuel consumption with CR 14 was found to be less than that of CR16 and CR18. Due to the effect of charge dilution at higher compression ratios engine consume more fuel for all the blends [8]. The fuel consumption for the B10CeO$_2$50 blend was found to be lowest among all the fuel blends at full load and all compression ratios. At CR 14 blend B10CeO$_2$50 found best and variation with increase in compression ratio of B10CeO$_2$50 blend is illustrated in figure 5.15.

Table 5.3: Fuel consumption at full load and CR 14, 16 and 18

Fuel consumption (kg/hr) at full load conditions			
CR	14	16	18
D100	0.65	0.66	0.68
B10	0.68	0.69	0.72
B10CeO$_2$50	0.63	0.64	0.66
B15	0.70	0.71	0.74
B15CeO$_2$50	0.65	0.66	0.68

5.2.4 Brake specific fuel consumption

5.2.4.1Effect of load and blend on brake specific fuel consumption

The test were performed for neat diesel fuel and then for different blends of biodiesel B10, B10$CeO_2$50, B15, B15$CeO_2$50 samples and the load on engine was varied from 0 to 6 kg at compression ratio 14,16 and 18 as shown in figure 5.16,5.17 and 5.18 . It was seen that BSFC decreased steeply with load for neat diesel and all blend of biodiesel at all the compression ratio. The main cause for this can be that amount of fuel required to run the engine is less than the percent increase in BP due to the less heat losses at higher loads [10]. The BSFC of biodiesel blends B15 and B10 was found to be experimentally higher than diesel fuel and nanoparticles added blends. As the percentage of biodiesel blend increased, the BSFC was found to be increased due to the higher density and lower calorific value of biodiesel. But when nanoparticle blended biodiesel with 50 PPM concentration was tested on CI engine then improvement was observed comparative to neat diesel, B10 and B15. This phenomenon happened due to the reduction in physical delay, high calorific value of nanofuels, enhanced surface area to volume ratio and combustion promoting characteristics of nanoparticles [6]. The lower BSFC was observed for B10$CeO_2$50 due to the higher CV among the all fuel, better atomization and good combustion characteristics. Result of all fuel blends at high load and all compression ratios is figured in table 5.4.

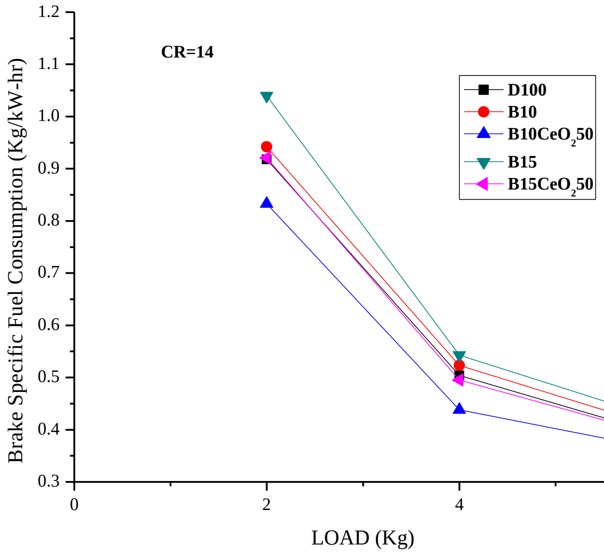

Figure 5.16: Variation of BSFC with respect to load at compression ratio 14

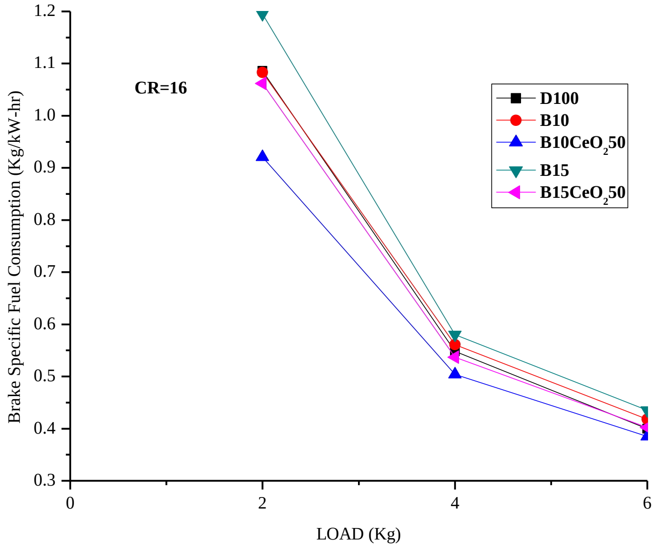

Figure 5.17: Variation of BSFC with respect to load at compression ratio 16

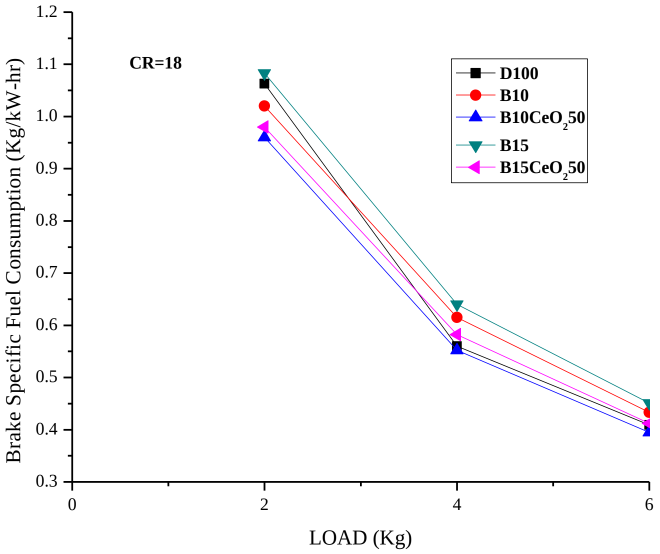

Figure 5.18: Variation of BSFC with respect to load at compression ratio 18

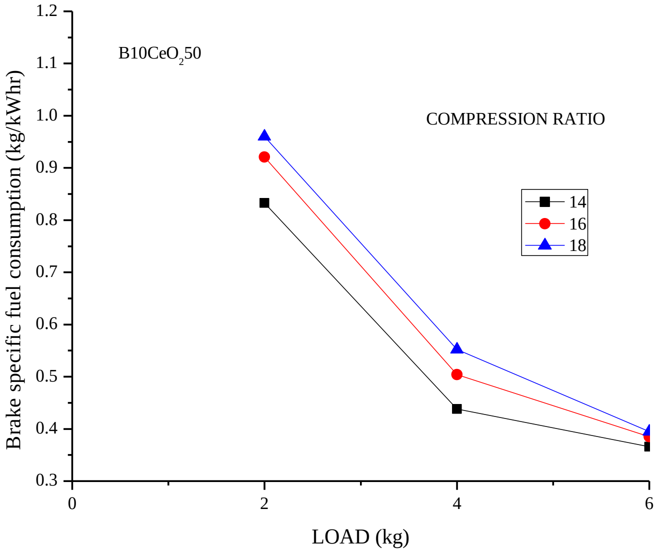

Figure 5.19: Variation of BSFC with respect to load of B10CeO$_2$50 at compression ratio 14, 16 and 18

5.2.4.2 Effect of compression ratio on brake specific fuel consumption

The BSFC was observed to be increased with the increase in compression ratio from 14 to 18. The BSFC with CR 14 was found to be less than that of CR16and CR18**.** This is mainly due to the charge dilution at higher compression ratio. The BSFC for the B10$CeO_2$50 blend was found to be lowest among all the fuel blends at full load and all compression ratios. Variation with increase in compression ratio of B10$CeO_2$50 blend is illustrated in figure 5.19.

Table 5.4: BSFC at full load and CR 14, 16 and 18

BSFC (kg/kW-hr) at full load conditions			
CR	14	16	18
D100	0.396	0.4	0.409
B10	0.409	0.418	0.433
B10$CeO_2$50	0.366	0.385	0.395
B15	0.426	0.435	0.451
B15$CeO_2$50	0.393	0.402	0.412

5.2.5 Exhaust gas temperature

5.2.5.1Effect of blend and load on exhaust gas temperature

Graphs for pure diesel as a base fuel and biodiesel blends B10, B10$CeO_2$50, B15 and B15$CeO_2$50 were obtained during the engine operation at variable load 0 to 6 kg and different compression ratio 14, 16 and 18. Results are shown in figure 5.20, 5.21 and 5.22.

It was observed experimentally that exhaust gas temperature of all the biodiesel blends included nanoparticle blends found to be more than pure diesel. Exhaust gas temperature of B15 was seen maximum among the all fuels. This is due to the higher amount of oxygen molecules in the ester form which takes part in the combustion process. It raises the combustion chamber temperature resulting in increase the exhaust gas temperature. The exhaust gas temperature was observed in increasing trend for all the fuel as the load was increased and maximum temperature was attained at full load. This is due to the more fuel burnt to maintain the constant speed. But after the addition of cerium oxide nanoparticles in the biodiesel blends improving trend was observed. The temperature of blend B10$CeO_2$50 was found to be lower at all loads and compression ratios as compare to other biodiesel blends. The EGT was seen least at full load and compression ratios 16 and 18 except the other conditions as compare to diesel. Same phenomenon was happened with B15$CeO_2$50 that shown improving trend as compare to B15. This is due to the positive effect of cerium oxide nanoparticles. This was reported that cerium oxide nanoparticles able to reduce the peak temperature inside the combustion chamber due to liberating and preserving ability of oxygen according to the following equation.

$$2CeO_2 \leftrightarrow Ce_2O_3+1/2O_2 \quad \ldots (1)$$

Due to the excess oxygen complete combustion takes place into the cylinder and less accumulation of deposit on the internal cylinder wall and increases the heat transfer rate to the cylinder wall by removing the insulation layer of non-polar compounds from the wall leading to lower exhaust gas temperature[4]. T. Shafi et al. also reported that alumina fuel blend decreased the exhaust gas temperature at all loading conditions due to the higher heat transfer coefficient of combustion products which reduced the sink temperature and improved the performance of engine [9]. Lower exhaust loss due to the lower exhaust gas temperature may be the feasible reason for higher performance [5]. Results at full load of exhaust gas temperature at different compression ratio are shown in table 5.5.

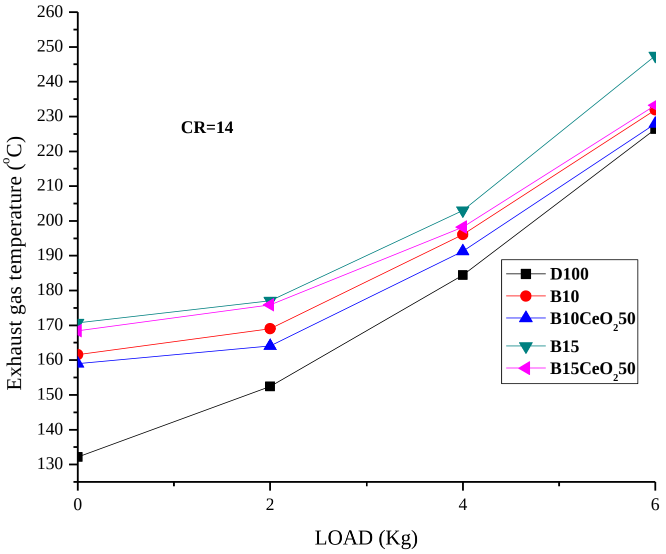

Figure 5.20: Variation of Exhaust gas temperature with respect to load at compression ratio 14

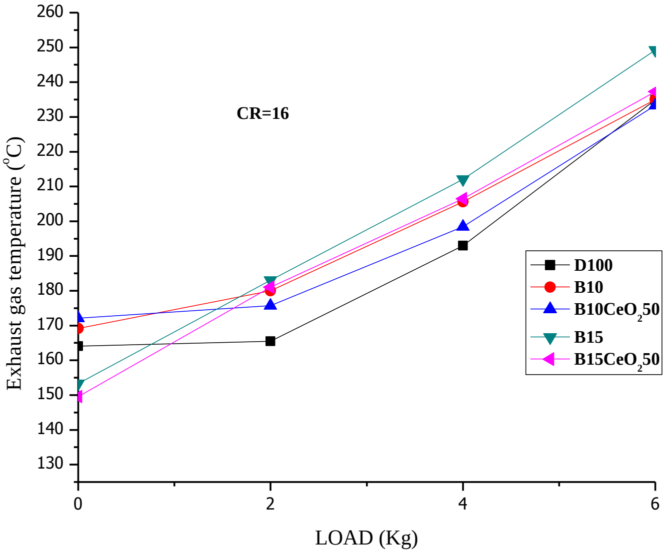

Figure 5.21: Variation of Exhaust gas temperature with respect to load at compression ratio 16

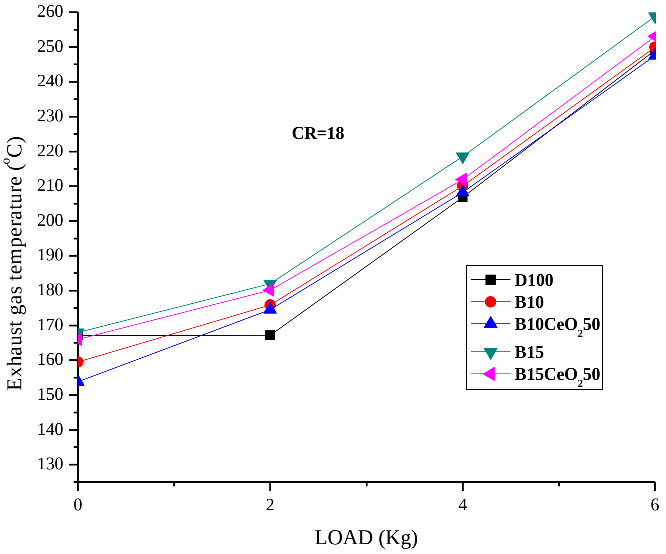

Figure 5.22: Variation of Exhaust gas temperature with respect to load at compression ratio 18

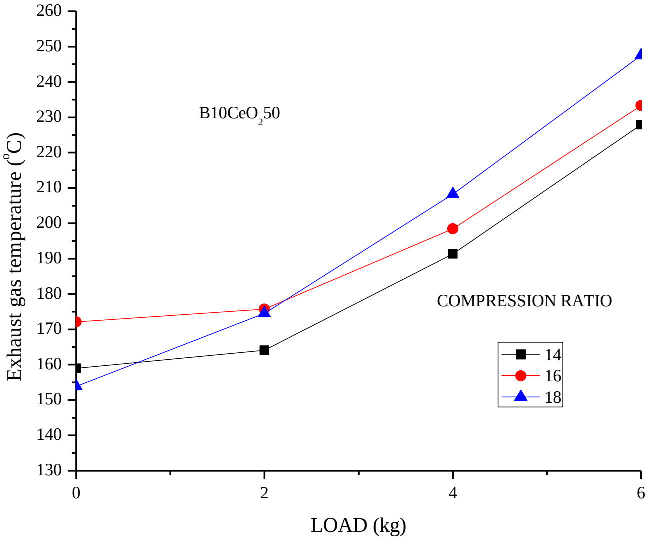

Figure 5.23: Variation of Exhaust gas temperature with respect to load of $B10CeO_250$ at compression ratio 14, 16 and 18

5.2.5.2 Effect of compression ratio on exhaust gas temperature

The exhaust gas temperature was observed to be increased with the increase in compression ratio from 14 to 18. The exhaust gas temperature with compression ratio 14 was found to be less than that of compression ratios 16 and 18**.** This is mainly due higher combustion chamber temperature at higher compression ratio and lower A/F ratio. The exhaust gas temperature for the B10CeO$_2$50 blend was found to be 227.93^{o}C but more than diesel at full load and compression ratio 14. However B10CeO$_2$50 blend shown least temperature at full load and compression ratio 16 and 18 among the all fuels included diesel. The temperature was obtained 233.31 ^{o}C and 247.53 ^{o}C and variation with increase in compression ratio of B10CeO$_2$50 blend is illustrated in figure 5.23.

Table 5.5: Exhaust gas temperature at full load and CR 14, 16 and 18

Exhaust gas temperature (^{o}C) at full load conditions			
CR	14	16	18
D100	226.38	234.91	249.09
B10	231.93	235.01	250
B10CeO$_2$50	227.93	233.31	247.53
B15	247.5	249.25	258.85
B15CeO$_2$50	233.24	237.27	253.07

5.3 Emission characteristics

5.3.1 NOx

5.3.1.1Effect of blend and load NOx emission

The variation of NOx with respect to load at compression ratio 14, 16 and 18 for different blends of biodiesel is shown in figure 5.24, 5.25 and 5.26. It was observed from the experiments that NOx pollutants of all the fuels were increased with the increase in load. This is due to the higher amount of fuel burnt. The NOx emissions of all biodiesel blends exhibited a little higher NOx than diesel. B15 blend of biodiesel shown highest NOx among the all fuels at all load. This phenomenon was happened due to the higher temperature achieved inside the combustion chamber because biodiesel is an oxygenated fuel. It provides additional oxygen to inhaled air into the combustion chamber which leads to complete combustion and raises the temperature of combustion chamber. At higher temperature nitrogen mixed with oxygen in air and more formation of NOx observed. Second reason is lower ignition delay of biodiesel promote complete combustion and chamber attained higher temperature. To overcome the problem additives was added to the biodiesel blends. The cerium oxide nanoparticles were mixed to biodiesel with 50 PPM concentration. The nanoparticle added biodiesel blends B10CeO$_2$50 and B15CeO$_2$50 were shown marginal reduction in NOx emission when compared with B10 and B15. It was observed that biodiesel blend B10CeO$_2$50 exhibited least NOx than all biodiesel blends but more than pure diesel at full load. This is due to the complete combustion takes place inside combustion chamber with higher temperature which prevents to deposit carbon on the cylinder wall and it improves the heat transfer coefficient through the cylinder wall which results in decreased NOx formation [4].

One more reason to reduce the NOx emission is that cerium oxide act as oxygen absorber in the combustion chamber and following reaction help to reduce the NOx pollutants.

$$Ce_2O_3+NO \leftrightarrow 2CeO_2+1/2N_2 \qquad \dots (2)$$

According to above reaction when it absorbs oxygen then leads to reduce the NOx. Results of NOx at full load and all compression ratios are shown in table 5.7.

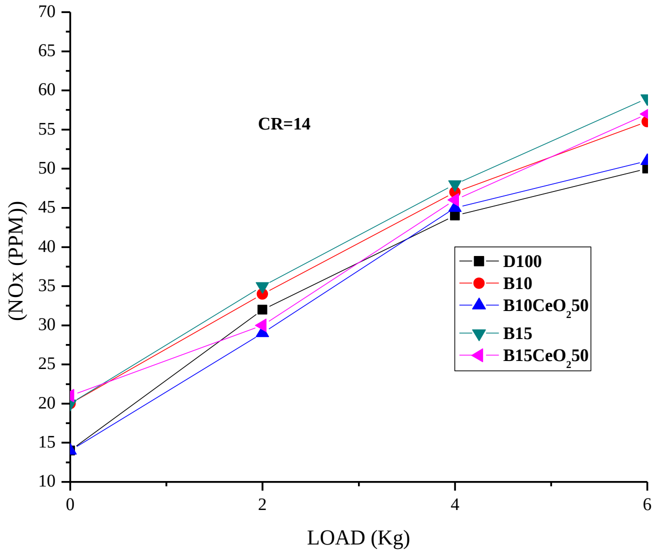

Figure 5.24: Variation of NOx with respect to load at compression ratio 14

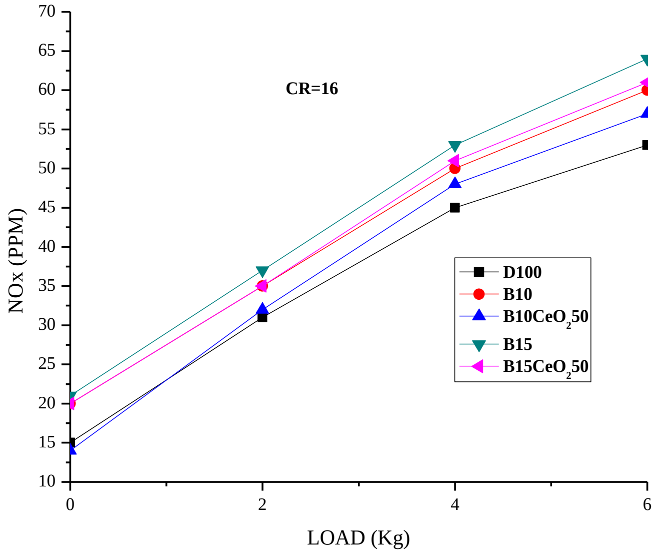

Figure 5.25: Variation of NOx with respect to load at compression ratio 16

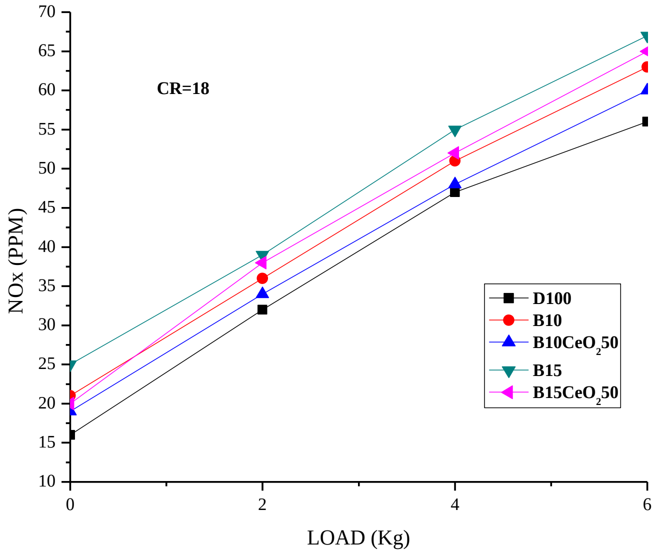

Figure 5.26: Variation of NOx with respect to load at compression ratio 18

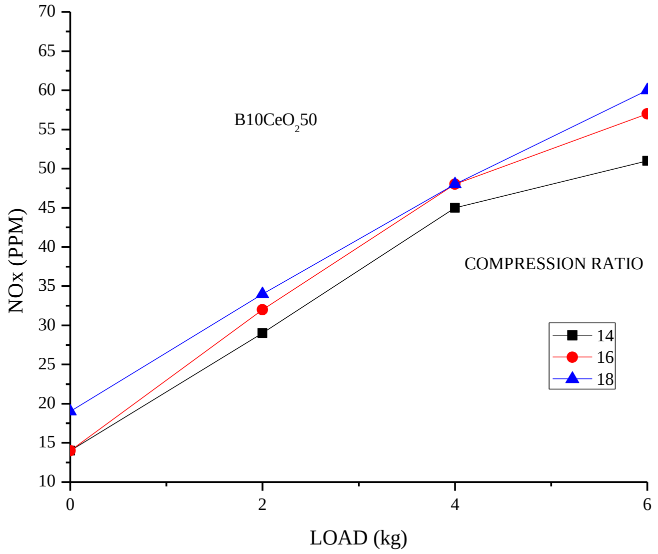

Figure 5.27: Variation of NOx with respect to load of B10CeO$_2$50 at compression ratio 14, 16 and 18

5.3.1.2 Effect of compression ratio NOx emission

The NOx emissions were observed to be increased with the increase in compression ratio from 14 to 18. This is clearly observed from the figure 5.27 that biodiesel blend B10CeO$_2$50 found to be optimum at compression ratio 14. This is due to the lower exhaust gas temperature. This is mainly due to the higher combustion chamber temperature which increased as the compression ratio increased due to lower ignition delay. B10CeO$_2$50 blend was shown 8.92% less NOx at full load than B10 and it was closely followed the pure diesel at all load and compression ratio. Variation NOx emission with increase in compression ratio of B10CeO$_2$50 blend is illustrated in figure 5.31.

Table 5.6: NOx at full load and CR 14, 16 and 18

NOx (PPM) at full load conditions			
CR	14	16	18
D100	50	53	56
B10	56	60	63
B10CeO$_2$50	51	57	60
B15	59	64	67
B15CeO$_2$50	57	61	65

5.3.2 CO

5.3.2.1 Effect of blend and load on CO emission

The variation of carbon monoxide emission with respect to load for neat diesel fuel and for different blends of biodiesel fuel B10, B10CeO$_2$50, B15, and B15CeO$_2$50 at compression ratio 14, 16 and 18 is illustrated in figure 5.28, 5.29 and 5.30. Carbon monoxide (CO) in compression ignition diesel engine is produced during the intermediate combustion stages. Compression ignition engine run well on the lean side of the stoichiometric air-to-fuel ratio. It was observed that pure diesel was emitted maximum CO among the all fuels. This is due to the inadequate oxygen to transform all carbon into carbon dioxide, some fuels are not complete burned and then carbon of fuel ends up as carbon monoxide. Also the poor mixing of fuel, local rich regions in the combustion chamber and incomplete combustion in the cylinder will also be the cause for CO emissions [11].

The biodiesel blends B10 and B15 were shown better improving and emitted lower CO as compare to pure diesel. This is due to 11% oxygen in the methyl esters. When dispersed 50 PPM concentration of cerium oxide nanoparticles to the biodiesel blends then it was revealed further improvement. B15CeO$_2$50 blend of biodiesel was revealed minimum CO at the all the load and compression ratio. This is due to the cerium oxide acts as oxygen buffer and provide sufficient amount of oxygen for the conversion of CO to CO_2 resulting complete combustion by following reaction [12, 4].

$$2CeO_2+CO \longleftrightarrow Ce_2O_3+CO_2 \qquad \ldots (3)$$

Addition of nanoparticles to the blending fuel causes rapid mixing and better atomization of fuel molecule takes place inside diesel engine. Thus it reduces the air requirement which in turn results in less conversion of unburned carbon molecule to CO. Results of CO at full load and compression ratios 14, 16 and 18 are shown in table 5.8.

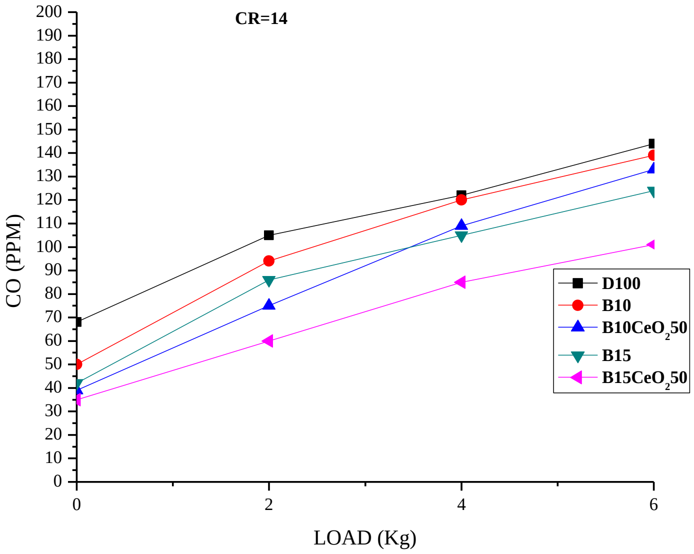

Figure 5.28: Variation of CO with respect to load at compression ratio 14

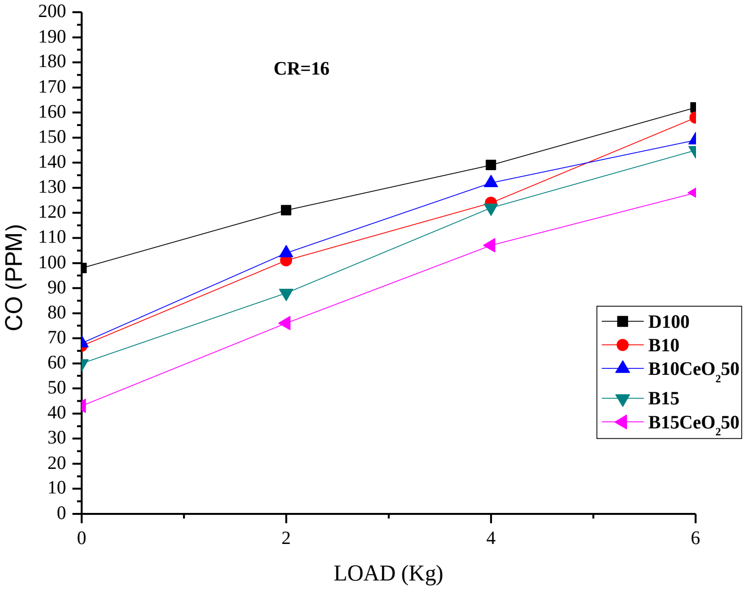

Figure 5.29: Variation of CO with respect to load at compression ratio 16

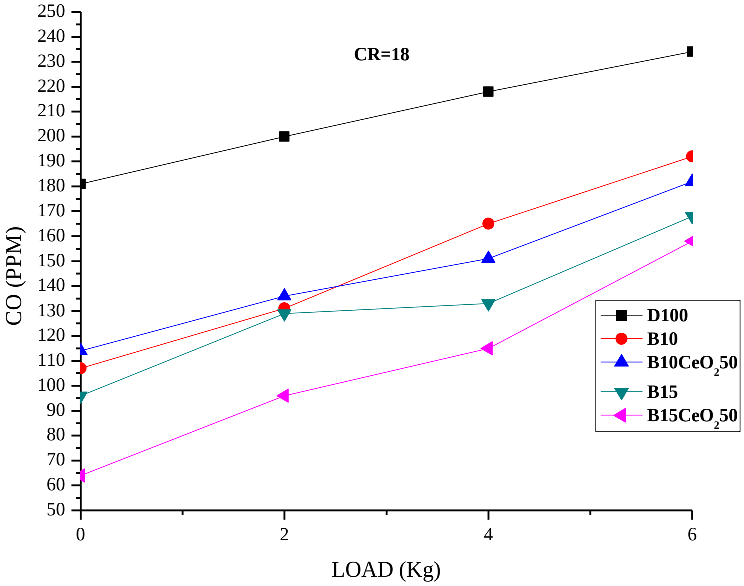

Figure 5.30: Variation of CO with respect to load at compression ratio 18

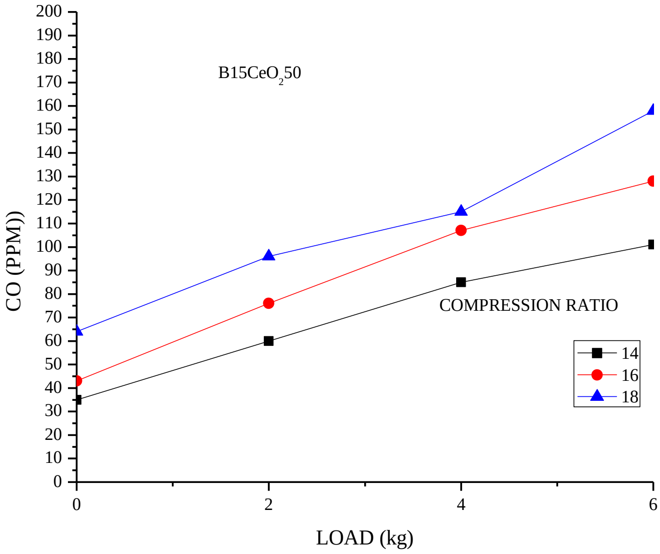

Figure 5.31: Variation of CO with respect to load of B15CeO$_2$50at compression ratio 14, 16 and 18

5.3.2.2 Effect of compression ratio on CO emission

The CO was observed to be increased with the increase in compression ratio from 14 to 18. The CO at compression ratio14 was found to be less than that of compression ratios16 and 18 due to the decrease in A/F ratio with the increase in compression ratio for all the blends. The lower compression ratio induces complete combustion due to lean air-fuel mixture near to stoichiometric ratio. The CO emission for the B15CeO250 blend was found to be least among all the fuel blends at all the load and compression ratio. The variation of CO with increase in compression ratio of B15CeO$_2$50 blend is illustrated in figure 5.31.

Table 5.7: CO at full load and CR 14, 16 and 18

Carbon monoxide (ppm) at full load conditions			
CR	14	16	18
D100	144	162	234
B10	139	158	192
B10CeO$_2$50	133	149	182
B15	124	145	168
B15CeO$_2$50	101	128	158

5.3.3 HC

5.3.3.1 Effect of blend and load on hydrocarbon emission

The variation of hydrocarbon emission with respect to load for neat diesel fuel and for different blends of biodiesel B10, B10CeO$_2$50, B15 and B15CeO$_2$50 at compression ratio 14, 16 and 18 are shown in figure 5.32, 5.33 and 5.34. Hydrocarbon in the exhaust directly indicates the incomplete combustion in combustion chamber of fuel molecules. It was observed experimentally that all the fuels emit hydrocarbon within the permissible limits and it was least for diesel, B10CeO$_2$50 and B15CeO$_2$50. At no load and compression ratios of 16 and 18, it was observed that higher amount of hydrocarbons for B10 and B15. This is due to the higher surface tension which promotes higher viscosity and lower compressibility while nanoparticles exposed more surface area and promote complete combustion which results in lower hydrocarbon [9].

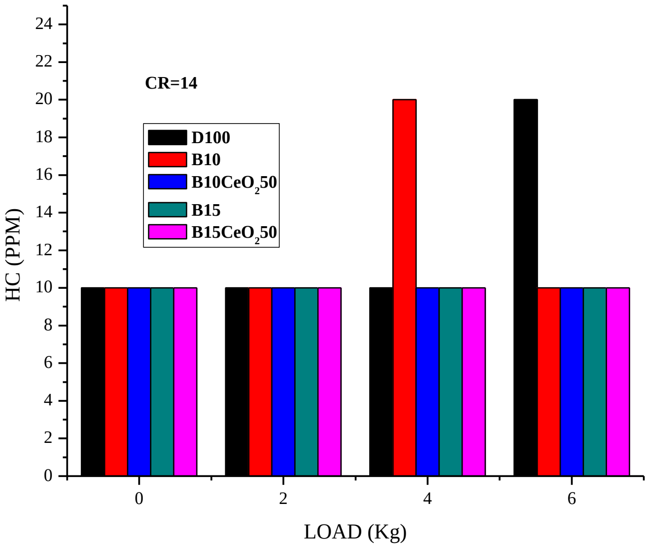

Figure 5.32: Variation of HC with respect to load at compression ratio 14

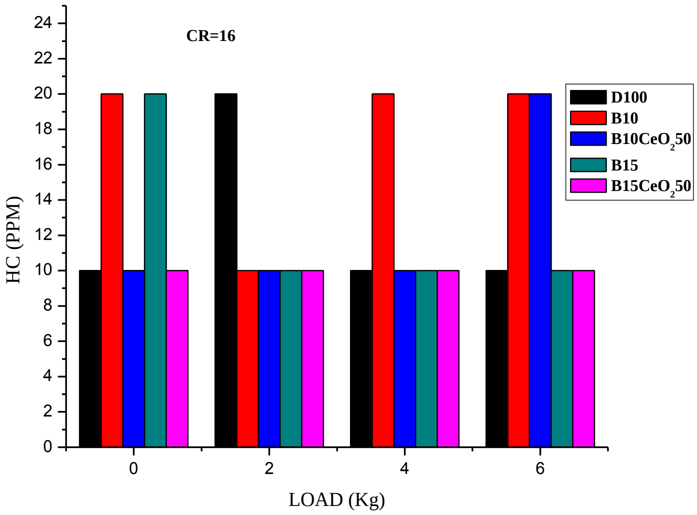

Figure 5.33: Variation of HC with respect to load at compression ratio

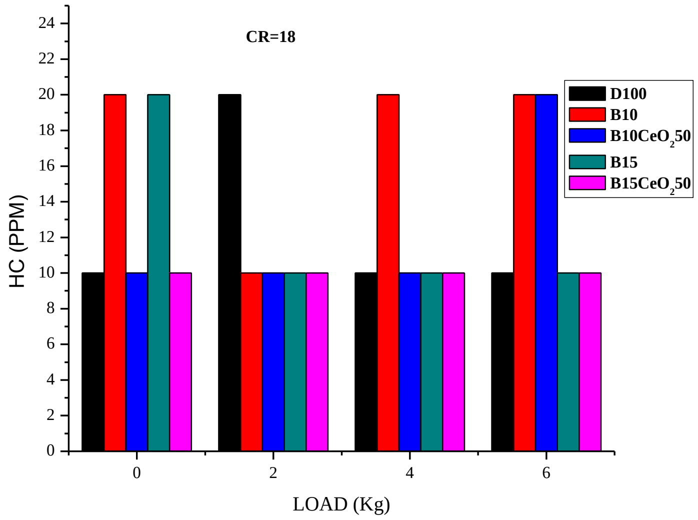

Figure 5.34: Variation of HC with respect to load at compression ratio 18

Table 5.8: HC at full load and CR 14, 16 and 18

HC (PPM) at full load conditions			
CR	14	16	18
D100	20	20	10
B10	10	10	20
B10CeO$_2$50	10	10	20
B15	10	10	10
B15CeO$_2$50	10	10	10

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CHAPTER 6

CONCLUSIONS

6.1 conclusions

The objective of present study is to investigate the effect of cerium oxide nanoparticles in the concentration of 50 PPM on the biodiesel blends. The nanoparticle added biodiesel blends were charged in variable compression ignition engine. The overall investigation of this work based on the manufacturing, fuel properties, performance and emission characteristics of different blends of biodiesel with and without nanoparticles were carried out. On the basis of present work conclusion can be described as following:

1. Fuel properties:

- The flash point and viscosity had straight relation to concentration of nanoparticles. It was seen that both flash point and viscosity were increased when added the nanoparticles to the blend.
- The nanoparticles are energetic material. The cerium oxide dispersed blends were shown higher gross calorific value than diesel. So the gross calorific value of blend B10$CeO_2$50 was 3.28% more than pure diesel.

2. Optimum compression ratio: The results were concluded at full load based on the experimental data:

- Brake power and Brake thermal efficiency were observed higher at compression ratio 14 for all the blends.
- Minimum fuel consumption and BSFC were observed at compression ratio 14.
- Minimum exhaust gas temperature was observed at compression ratio 14.
- Lowest CO and NOx emission were observed at compression ratio 14.

Based on the above conclusion compression ratio 14 was observed optimum.

3. Performance and emission characteristics comparison for optimum blend: All the conclusions were described at full load and compression ratio 14, 16 and 18:

- The entire nanoparticle added blend shown improving trend for BP. But at all the compression ratio had not shown any considerable difference in BP. The blend B10$CeO_2$50 was released 1.72 kW maximum power among the all fuels at CR 14. This was 4.87 % and 3.61% more than that of pure diesel and B10. The BP of B10 was slightly higher than pure diesel due to the complete combustion.
- The brake thermal efficiency was seen higher for B10$CeO_2$50 at CR 14 than CR 16 and 18. The BTE of B10$CeO_2$50 was evaluated 4.72% and 6.37% higher than base fuel diesel and B10.
- The minimum fuel consumption was observed for B10$CeO_2$50 at CR 14 which was 0.63 Kg/hr where it was for diesel, B10 were 0.65 Kg/hr and 0.68 Kg/hr respectively.
- Nearly same BSFC was observed for pure diesel and B15$CeO_2$50 at full load and CR 14. The lowest brake specific fuel consumption was observed for B10$CeO_2$50 at full load and CR 14 which was 0.366 kg/kW-hr where as it was for diesel and B10 were 0.396 kg/kW-hr and 0.409 kg/kW-hr respectively.
- It was experimentally calculated that the exhaust gas temperature of the all blends and pure diesel increases as the load and CR increases. The EGT of nanoparticle added blends were shown slightly higher than that of diesel. The EGT of B10$CeO_2$50 was observed 227.93 ^oC while the EGT for D100, B10,B15$CeO_2$50 and B15 were indicated 226.38 ^oC, 231.93 ^oC,233.24 ^oC,247.5 ^oC at full load and CR 14 respectively, which was lowest than CR 16 and 18.
- The magnitude of NOx of cerium oxide nanoparticles blended biodiesel blend was decreased compared to B10 and B15. Nearly same magnitude was observed for B10$CeO_2$50 and pure diesel. Minimum NOx emission magnitude was observed for B10$CeO_2$50 at CR 14. The magnitude of NOx for pure diesel, B10$CeO_2$50, B10, B15$CeO_2$50 and B15 were observed 50 PPM, 51 PPM, 56 PPM, 57 PPM, 59 PPM at CR 14 and full load. Maximum NOx was decreased up to 8.92% for B10$CeO_2$50 compared to B10 at full load and CR 14 respectively.

- CO emissions hold direct relation to complete combustion. Nanoparticles added biodiesel blend shown better reduction in harmful emission CO at all loads and compression ratio. Maximum decline was observed at CR 14. The CO was decreased by up to 29.86% and 7.63% respectively, in B15Ce$O_2$50 and B10Ce$O_2$50 compared to neat diesel.
- Hydrocarbon emission was observed within the permissible limit.

Based on the above conclusion blend B10Ce$O_2$50 found to be optimum. The results concluded that B10Ce$O_2$50 was performed best for all the performance and emission parameter except CO emission.

FUTURE SCOPE

Nanofuels from biodiesel can play vital role as an automotive fuel due to its improving performance characteristics and lower emissions over the base fuel diesel. The following points may be considered before introducing the fuel in India:

- The compatibility of cerium oxide was only studied. There is scope to study other compatibility of other material to improve the performance and overcome the emissions.
- Particle average size 10-30 nm was only studied. The effect of variable size of nanomaterials may be investigated on the agglomeration.
- When nanofluid used then stability is big problem. In this study long term stability was not studied. There is a scope to evaluate the long term stability by using the suitable surfactant.
- Effect of agitation speed, sonication time and surfactant concentration may be studied.
- Nanoparticles was not collected at end of the exhaust in this studied. There is a scope to collect the nanoparticles and may be investigate effect on performance, emission and properties.
- The engine was tested for only small time period so there is a possibility to conduct the prolonged operation to investigate the durability of this engine.
- The performance and emission characteristics of nanoparticles blended biodiesel were studied at load and different compression ratio. So experiments may be performed by changing the other parameters like speed, injection timing, ignition delay and nozzle.
- The effect of nanofuels on wear and tear was not studied. There is a scope to study the tribology properties of the nanofuels.
- Rule and regulation frame should be strong to implement the nanofuels.
- It should be subsidized due to higher initial cost.
- Complete environmental analysis should be done nanofuels.
- Further studies may also be carried out on material storage, compatibility and utilization of nanofuels.

APPENDIX

A. Nanoparticles

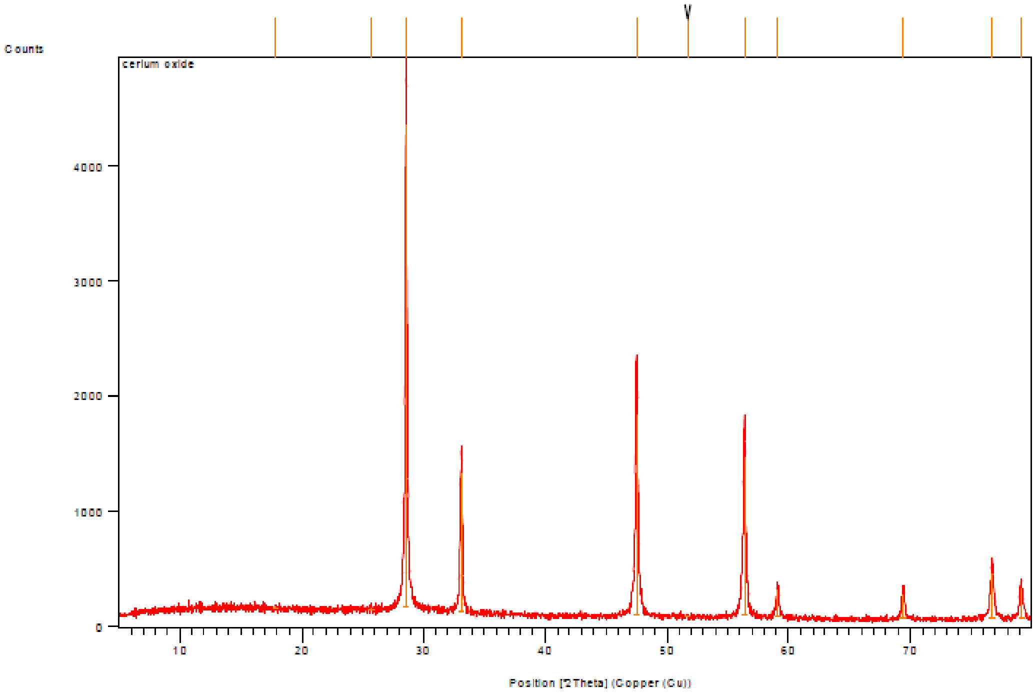

Figure A.1: XRD image of cerium oxide nanoparticles

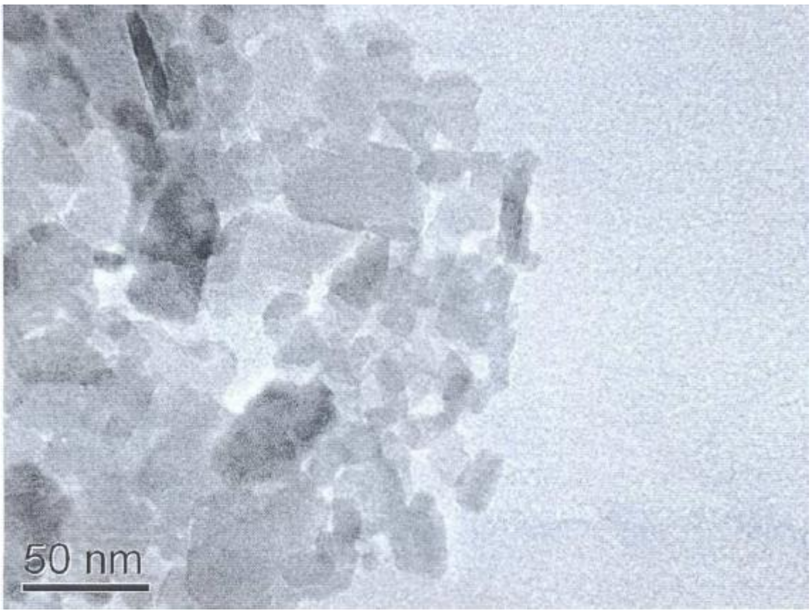

Figure A.2: SEM image cerium oxide nanoparticles

Table A.1: Cerium Oxide nanoparticles specification

Average particle size	10-30 nm
Purity	99.97%
Specific surface area	30-50 m^2/g
Color	Light yellow
Bulk density	0.8-1.1 g/cm^3
True density	7.132 g/cm^3

B. FUEL PROPERTIES

Table B.1: Fuel properties of different biodiesel blends compared to diesel

Sr. No.	**Properties**	**D100**	**B100**	**B10**	**B10CeO$_2$50**	**B15**	**B15CeO$_2$50**
1	**GCV, Kcal/kg**	10566	8711	10381	10913	10359	10692
2	**Viscosity @ 40 ^{o}C, mm^2/sec**	3.9	6.13	4.26	5.21	4.88	5.25
3	**Flash Point, ^{o}C**	46	200	60	63	72	74
4	**Density, gm/ml**	0.8175	0.8619	0.822	0.8248	0.824	0.8266

C. Experimental data of engine performance test

Table C.1: Results of BP for all fuels at different loads and compression ratios (KW)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	0	0	0	0	0
	2	0.49	0.52	0.54	0.5	0.51
	4	1.03	1.05	1.14	1.03	1.07
	6	1.64	1.66	1.72	1.64	1.65
16	0	0	0	0	0	0
	2	0.46	0.48	0.51	0.46	0.48
	4	1.04	1.05	1.09	1.05	1.08
	6	1.65	1.65	1.66	1.63	1.64
18	0	0	0	0	0	0
	2	0.47	0.5	0.5	0.48	0.51
	4	1.07	1.04	1.05	1.03	1.03
	6	1.66	1.66	1.67	1.64	1.65

Table C.2: Results of BTE for all fuels at different loads and compression ratios (%)

CR	LOAD (KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	0	0	0	0	0
	2	8.86	8.7	9.46	7.98	8.73
	4	16.13	15.82	17.97	15.27	16.24
	6	20.55	20.23	21.52	19.45	20.42
16	0	0	0	0	0	0
	2	7.49	7.65	8.55	6.94	7.57
	4	14.85	14.75	15.62	14.29	14.98
	6	20.36	19.82	20.45	19.06	19.99
18	0	0	0	0	0	0
	2	7.65	8.12	8.21	7.66	8.2
	4	14.52	13.46	14.27	12.96	13.81
	6	19.87	19.1	19.95	18.4	19.52

Table C.3: Results of FC for all fuels at different loads and compression ratios (kg/hr)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	0.25	0.35	0.26	0.35	0.28
	2	0.45	0.49	0.45	0.52	0.47
	4	0.52	0.55	0.5	0.56	0.53
	6	0.65	0.68	0.63	0.7	0.65
16	0	0.35	0.39	0.34	0.41	0.37
	2	0.5	0.52	0.47	0.55	0.51
	4	0.57	0.59	0.55	0.61	0.58
	6	0.66	0.69	0.64	0.71	0.66
18	0	0.4	0.42	0.39	0.45	0.43
	2	0.5	0.51	0.48	0.52	0.5
	4	0.6	0.64	0.58	0.66	0.6
	6	0.68	0.72	0.66	0.74	0.68

Table C.4 Results of BSFC for all fuels at different loads and compression ratios (Kg/KW-hr)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	0	0	0	0	0
	2	0.918	0.942	0.833	1.04	0.921
	4	0.504	0.523	0.438	0.543	0.495
	6	0.396	0.409	0.366	0.426	0.393
16	0	0	0	0	0	0
	2	1.086	1.083	0.921	1.195	1.062
	4	0.548	0.561	0.504	0.58	0.537
	6	0.4	0.418	0.385	0.435	0.402
18	0	0	0	0	0	0
	2	1.063	1.02	0.96	1.083	0.98
	4	0.56	0.615	0.552	0.64	0.582
	6	0.409	0.433	0.395	0.451	0.412

Table C.5: Results of EGT (^{o}C) for all fuels at different loads and compression ratios

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	132.14	161.59	159	170.71	168.45
	2	152.44	169.05	164.1	177.04	175.91
	4	184.43	196.06	191.32	203	198.24
	6	226.38	231.93	227.93	247.5	233.24
16	0	164.1	169.16	172.12	153.34	149.56
	2	165.5	180	175.75	183	181
	4	192.99	205.59	198.46	212.05	206.46
	6	234.91	235.01	233.31	249.25	237.27
18	0	167.08	159.48	153.83	168.02	166
	2	167.19	175.89	174.52	182.02	180.17
	4	206.83	210.07	208.25	218.57	211.95
	6	249.09	250	247.53	258.85	253.07

Table C.6: Results of NOx for all fuels at different loads and compression ratios (PPM)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	14	20	14	20	21
	2	32	34	29	35	30
	4	44	47	45	48	46
	6	50	56	51	59	57
16	0	15	20	14	21	20
	2	31	35	32	37	35
	4	45	50	48	53	51
	6	53	60	57	64	61
18	0	16	21	19	25	20
	2	32	36	34	39	38
	4	47	51	48	55	52
	6	56	63	60	67	65

Table C.7: Results of CO for all fuels at different loads and compression ratios (PPM)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	68	50	39	42	35
	2	105	94	75	86	60
	4	122	120	109	105	85
	6	144	139	133	124	101
16	0	98	67	68	60	43
	2	121	101	104	88	76
	4	139	124	132	122	107
	6	162	158	149	145	128
18	0	181	107	114	96	64
	2	200	131	136	129	96
	4	218	165	151	133	115
	6	234	192	182	168	158

Table C.8: Results of HC for all fuels at different loads and compression ratios (PPM)

CR	LOAD(KG)	D100	B10	B10CeO$_2$50	B15	B15CeO$_2$50
14	0	10	10	10	10	10
	2	10	10	10	10	10
	4	10	20	10	10	10
	6	20	10	10	10	10
16	0	10	20	10	10	10
	2	10	10	10	20	10
	4	10	10	20	10	10
	6	20	10	10	10	10
18	0	10	20	10	20	10
	2	20	10	10	10	10
	4	10	20	10	10	10
	6	10	20	20	10	10