Effect of TiO_2 Nanoparticle Blended Water Diesel Emulsion Fuel on CI Engine Performance and Emission Characteristics

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***Abstract*—Environmental degradation due to increase in pollution is the serious problem in the front of whole world. This problem further deteriorates with the depletion of natural resources. In addition, the fight against the inflation in energy prices and the dependency on the foreign oil has intensified the efforts to develop alternative fuel. A number of alternative fuels (emulsions, biodiesels etc.) have already been discovered, but most of them are still in research and development sector.**

Due to the superior properties of nanofluids, many researchers have examined the impact of varies nanoparticles on the performance and emission characteristics of compression ignition engine but most of the current research have been focused solely on nanoparticles dispersed in diesel or biodiesel as base fluid.

In the present work, the effect of titanium oxide nanoparticle blended water-diesel emulsion on the performance and emission characteristics of constant speed (1500 rpm) VCR diesel engine are studied. Water-diesel emulsions with 10% and 15% water by volume are used as a base fluid for the addition of 50 ppm and 70 ppm titanium oxide nanoparticles. All the prepared blends are examined at compression ratio 18 with varying loads and the obtained results of performance and emission are compared with that of conventional diesel. All the results are compared and it is concluded that the titanium oxide nanoparticle blended water diesel emulsion not only enhance the performance characteristics (brake power, brake specific fuel consumption, brake thermal efficiency) but also helps in the reduction of harmful emissions from compression ignition engines (unburned hydrocarbon, carbon monoxide).

Keywords*—*Micro-explosion; Hydrophilic lipophilic balance; Engine performance; Emission; Nano-fluids

I. INTRODUCTION

Compression Ignition (CI) engines have a significant role in transportation, agriculture, heavy industries and power generation due to their high power to weight ratio, better fuel economy and low breakdown rate. In spite of the numerous advantages of CI engine over spark ignition (SI) engine, they are also responsible for nearly forty harmful pollutants such as nitrogen oxides (NO_x), unburned hydrocarbon (HC), particulate matter (PM), sulphur oxides (SO_x), carbon monoxide (CO) and carbon dioxide (CO_2), etc [1, 2, 3].

The emission mixture from CI engine contains very small size carbon particles having size less than one micron. These particles combine with hazardous compounds and inhaled into the lungs due to their small size and cause several types of problems like allergies, asthma attack and lung cancer [3]. Further, diesel flumes are more carcinogenic and it is believed that the potential of diesel vehicles exhaust to cause cancer is double as compared to the exhaust from petrol run vehicles.

The current state of energy prices and the dependency on the foreign oil has intensified the efforts to develop alternative fuel. The Pollution Conservation Research Association have reported that the transport sector solely accountable for more than 50% of the entire oil consumption in the country. It is found that diesel engine emits forty different types of pollutants, but out of them NO_x, CO, UHC, PM, black smoke, SO_x and CO_2 are emitted in large amounts as compared to others [3]. Increasing stringent regulation on exhaust emissions drives a major research endeavour in engine development in order to cut down these pollutants [4].

From the past several years, research is going on to tackle these problems by providing hardware and fuel based solutions. Modern hardware solutions to control pollution are piezo-injectors, high-pressure fuel injection equipment, exhaust gas recirculation system and diesel particulate filters [5-8]. However, the problem with these systems is that they require modification in the existing engines which is time consuming and costly. On the other hand, fuel based solutions are viewed as a possible as well as economical solution which can solve both the problems (emission and depletion of resources) at the same time. Various fuel-based solutions are:

- Biodiesels,
- Water-diesel emulsion,
- Nano-fluids.

II. EXPERIMENT DETAILS

The water diesel emulsion fuel with and without titanium oxide nanoparticles was charged into a variable compression ignition diesel engine to analyze its behaviour at compression ratio 18. The performance parameters of compression ignition engine such as brake power, specific fuel consumption, brake mean effective pressure, brake thermal efficiency, etc were found with the help of ICEngineSoft software provided by Apex Innovations Private Limited. Whereas, pollutants such as CO, HC and NO_x was analyzed with the help of ACE Maxicem 9000 exhaust gas analyzer. TABLE I. shows the specifications of the exhaust gas analyzer.

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TABLE I. SPECIFICATION OF ACE MAXICEM 9000

Parameters	Range	Accuracy	Resolution
O_2	0 - 21 %	± 2 % of reading	0.1 %
CO	0 - 5000 ppm	± 5 % of reading	1 ppm
Thermocouple	0 - 600 ºC	± 3 % of reading	1 ºC
SO_2	0 - 5000 ppm	± 5 %	1 ppm
NO_x	0 - 5000 ppm	± 5 %	1 ppm

A. *Fuel preparation*

The preparation of fuel was done in two parts: first, water-diesel emulsion preparation with 10 % and 15 % water content by volume; second, titanium oxide nanoparticle blended water-diesel emulsion fuel with 50 ppm and 70 ppm nanoparticle concentration. Water-diesel emulsion was prepared by dispersing 10 % water content by volume into diesel fuel. Surfactant mixture of two surfactants (Tween 80 and Span 80) was prepared to get the desired value of hydrophilic and lipophilic balance of value 8. The prepared surfactant mixture was added into the diesel fuel. After stirring it with the help of mechanical agitator, water (10 % by volume) was added gradually into it and then stirring was done for another 30 minutes. In order to achieve higher stability of water-diesel emulsion fuel, the sample was then placed in an ultrasonicator. The resultant product yields water-diesel emulsion with 10 % water (E10). The similar procedure was adopted for the preparation of water-diesel emulsion with 15 % water content (E15).

Titanium oxide nanoparticles were used to examine the effect of nanoparticle blended water-diesel emulsion fuel on compression ignition engine. TABLE II. shows the specifications of TiO_2 nanoparticles. Hexadecyltrimethyl ammonium bromide (CTAB) was used as a surfactant for dispersing titanium oxide nanoparticle into water-diesel emulsion. For the preparation of titanium oxide nanoparticle blended water-diesel emulsion fuel: first, Hexadecyltrimethyl ammonium bromide (CTAB) surfactant was added into water with the help of magnetic stirrer. Titanium oxide nanoparticle (50 ppm) was added gradually into it and then stirring was done. After that, the prepared nanofluid was dispersed in diesel (88 % by volume) with the help of stirring and ultrasonication. The resultant product yields the titanium oxide nanoparticles blended water-diesel emulsion (E10$TiO_2$50). The similar procedure was adopted for the dispersion of 70 ppm nanoparticles in E10 and 50 ppm and 70 ppm nanoparticles in

TABLE III. PROPERTIES OF TESTED FUELS

Fuels	Properties			
	Calorific value (kJ/kg)	*Density* (g/cc)	*Viscosity* (mm^2/sec)	*Flash point* (ºC)
D	44630	0.8298	2.5	55
E10	39788	0.8435	4.13	66
E10$TiO_2$50	40893	0.8442	4.19	69
E10$TiO_2$70	41689	0.8447	4.23	71
E15	37457	0.8504	4.81	69
E15$TiO_2$50	38653	0.8512	4.88	72
E15$TiO_2$70	39987	0.8516	4.91	75

TABLE II. SPECIFICATION OF TiO_2 NANOPARTICLES

Item	Specification
Purity	99.97%
Average particle size	10-25 nm
Bulk density	0.15- 0.25 g/cm^3
True density	3.9 g/cm^3
Colour	White

E15, for the yield of E10$TiO_2$70, E15$TiO_2$50 and E10$TiO_2$70, respectively. The fuel properties of diesel and water diesel emulsion with and without titanium oxide nanoparticles are shown in TABLE III.

B. *Test Setup*

A 4-stroke, single cylinder, VCR diesel engine was utilized for evaluating the performance characteristics. All the blends of emulsion fuel were tested on a variable compression ignition engine to analyze its behaviour at different loads and compression ratio 18.

The arrangement for measurement of airflow, fuel flow, temperature and load was provided. Fuel tank, Air box, manometer, transmitters for air, fuel flow measurements and fuel measuring unit, engine indicator and process indicator has been assembled separately in the panel box. Rotameter was used to control the flow of water through calorimeter and interconnected water jackets around cylinder block and head. Load cell sensor was used to vary the load on an eddy current dynamometer that is coupled to the engine. Labview based Engine Performance Analysis software package "Enginesoft" was provided for online performance evaluation. Fig. 1. shows the schematic view of the experimental setup whereas; the engine specifications are listed in TABLE IV.

III. RESULTS AND DISCUSSION

A. *Comparison of Performance Characteristics*

1) Brake Power (BP). The experiment on the VCR diesel engine was conducted with diesel and six blends of water diesel emulsion (E10, E10$TiO_2$50, E10$TiO_2$70, E15$TiO_2$50

TABLE IV. ENGINE SPECIFICATIONS

Engine	4-Stroke, Single Cylinder, Water Cooled, VCR Engine
Make Type	Kirloskar
Bore x Stroke	87.5 mm x 110 mm
Length of Connecting Rod	234 mm
Rated Power	3.75 kW @1500 rpm
Compression Ratio	12 – 18
Loading device	Eddy current dynamometer
Rotameter	Calorimeter 25-250 L/h ; Engine cooling 40-400 L/h
Temperature sensor	Thermocouple, Type K
Speed indicator	Digital with non contact type speed sensor

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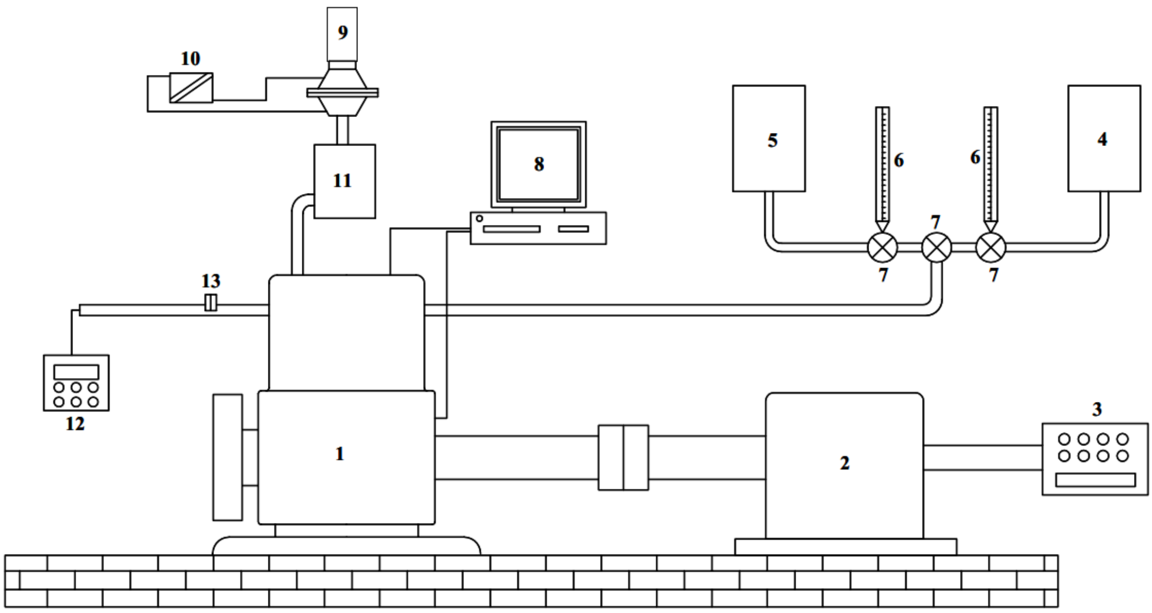

Fig. 1. Schematic diagram of experimental setup.

(1) VCR Diesel Engine	(2) Alternator	(3) Loading Device	(4) Emulsion 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 Analyser
(13) Exhaust Gas Temperature Sensor			

E15, E15TiO$_2$70) at compression ratio 18. During the experiment, the load on the engine was varied. The variation of brake power with respect to load is shown in Fig. 2. From the above-mentioned figure, it is apparent that brake power increases with the increase in load on the engine due to the consumption of more fuel [9]. It is found that at low load conditions, the brake power for conventional diesel and E10, E10TiO$_2$50, E10TiO$_2$70, E15, E15TiO$_2$50 and E15TiO$_2$70 is almost same. At higher loads, marginal difference is detected for the all fuels, but this difference is insignificant. This is mainly due to complete combustion takes place inside the combustion chamber due to the micro-explosion phenomenon of water-diesel emulsion. A slight drop in the brake power is reported with E15. This is due to lower calorific value of E15 that is nearly 16 % lower than the calorific value of pure diesel. Addition of titanium oxide nanoparticles to water-diesel emulsion shows slight rise in brake power at higher load

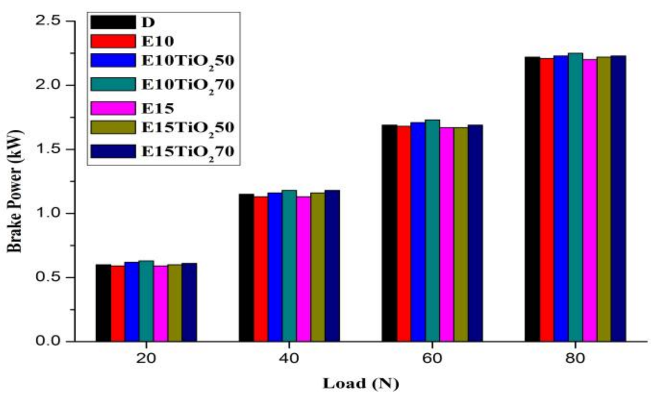

Fig. 2. Variation of brake power with respect to load.

due to secondary atomization of nanofluids. At higher loads, E10TiO$_2$70 shows maximum brake power.

2) Brake thermal efficiency. The brake thermal efficiency of diesel, E10, E10TiO$_2$50, E10TiO$_2$70, E15, E15TiO$_2$50 and E15TiO$_2$70 is demonstrated in Fig. 3. Rise in brake thermal efficiency is reported with increase in load for all the prepared fuels and diesel. It is also observed that the brake thermal efficiency of E15 is lesser than E10 due to lower calorific value, lower volatility, higher density, higher viscosity and higher fuel consumption. Improvement in brake thermal efficiency is obtained for both water-diesel emulsions (E10 and E15) and titanium oxide nanoparticle blended water diesel emulsions (E10TiO$_2$50, E10TiO$_2$70, E15TiO$_2$50 and E15TiO$_2$70) as compared to diesel. Further, it is noted that brake thermal efficiency also increases with the dosing level

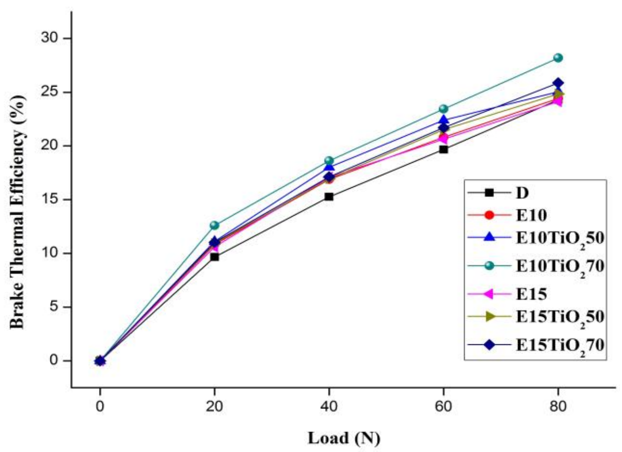

Fig. 3. Variation of brake thermal efficiency with respect to load.

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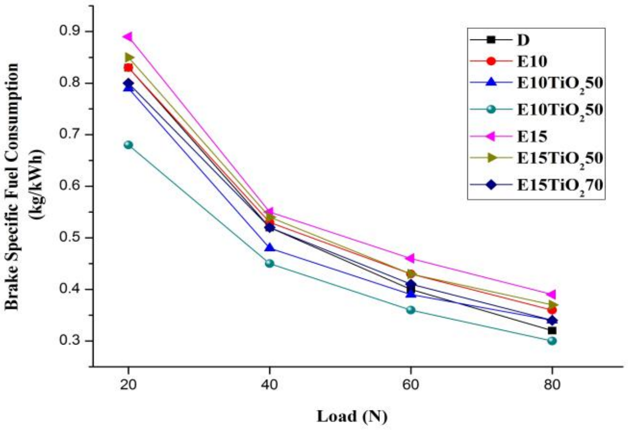

Fig. 4. Variation of brake specific fuel consumption with respect to load.

of a titanium oxide nanoparticle in both E10 and E15. Among all the prepared fuels $E10TiO_270$ shows maximum brake thermal efficiency at full load which is nearly 3.89 % higher than diesel. This can be due to secondary atomization of titanium oxide nanoparticle encapsulated water molecule immediately after the primary micro explosion phenomenon of water-diesel emulsion. Further, the presence of nanoparticle in fuel helps in complete combustion because of higher evaporation rates, shorter physical ignition delay, prolonged flame sustenance and higher calorific value.

3) Brake Specific Fuel Consumption. The variation of brake specific fuel consumption for diesel and different blends of emulsified fuel at different loads is reported in Fig. 4. Decrease in brake specific fuel consumption is noticed with the rise in load on engine for all the fuels. Among all the prepared fuels, E15 shows maximum brake specific fuel consumption. This can be due to higher fuel consumption and lower calorific value of E15 [9, 10, 11]. Improvement in brake specific fuel consumption is observed with the addition of nanoparticles. The lowest brake specific fuel consumption is observed with $E10TiO_270$. This can be due to the presence of titanium oxide nanoparticles in water-diesel emulsion [12].

B. Comparison of Emission Characteristics

1) Nitrogen Oxide (NO_x) emission. The main reason behind the formation of NO_x emission from compression ignition engine is dissociation of gases at high temperature. The variation of NO_x emission with respect to load at compression ratio 18 for diesel, E10, $E10TiO_250$, $E10TiO_270$, E15, $E15TiO_250$ and $E15TiO_270$ is shown in Fig. 5. It is found that the water-diesel emulsion with 15% water content produce the least amount of NO_x emission as compared to other fuels [10]. Reason behind this reduction is the decrease in peak cycle temperature due to the vaporization of water molecules present in water-diesel emulsion. Further, it is found that the addition of nanoparticles rise the NO_x emission [13]. Among all the prepared fuel, $E10TiO_270$ shows the maximum amount of NO_x emission. This can be due to increase in peak cycle temperature with the addition of nanoparticles.

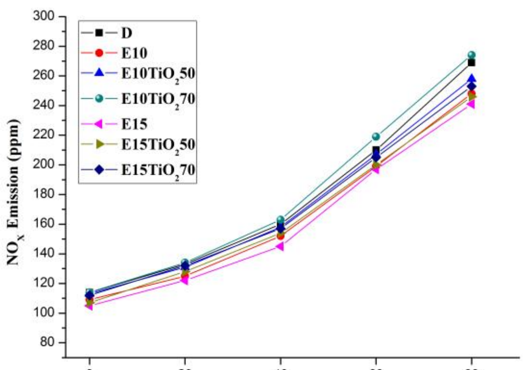

Fig. 5. Variation of NO_x emission with respect to load.

2) Hydrocarbon (HC) Emission. The main reason behind the formation of unbrunt hydrocarbon emission from compression ignition engine is incomplete combustion of heterogeneous mixture due to formation of local rich mixture spots. The variation of unbrunt hydrocarbon emission with respect to load at compression ratio 18 for diesel, E10, $E10TiO_250$, $E10TiO_270$, E15, $E15TiO_250$ and $E15TiO_270$ is shown in Fig. 6. It is observed that the water-diesel emulsion with 15% water content produce higher amounts of hydrocarbon emission as compared to other fuels. This can be due to the presence of water, which decrease localized temperature in the combustion chamber.

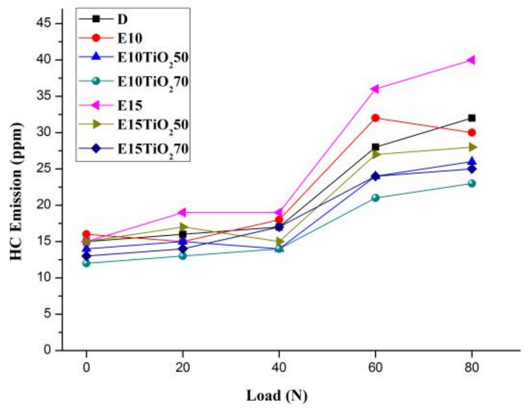

Fig. 6. Variation of HC emission with respect to load.

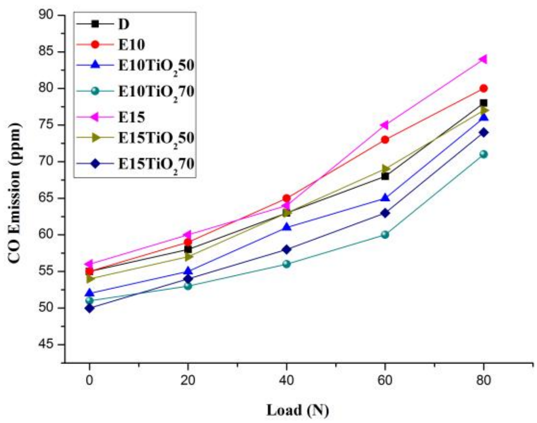

Fig. 7. Variation of CO emission with respect to load.

Moreover, longer ignition delay and higher viscosity of E15 can also be responsible for increase in unbrunt hydrocarbon emission [14]. Further, it is observed that the addition of nanoparticles helps in the reduction of hydrocarbon emission. Among all the prepared fuel, E10TiO$_2$70 shows the least amount of hydrocarbon emission. This can be due to improvement in combustion with the addition of nanoparticles.

3) Carbon Monoxide (CO) emission. The CO emission for diesel, E10, E10TiO$_2$50, E10TiO$_2$70, E15, E15TiO$_2$50 and E15TiO$_2$70 is demonstrated in Fig. 7. Rise in CO emission is observed with increase in load for all the prepared fuels and diesel. It is also found that CO emission of E15 and E10 is higher than diesel [10, 11, 14]. This increase in CO emission is due to short oxygenating time for CO gas because of reduction in temperature of combustion products. This reduction in temperature is due to the presence of water in the combustion chamber. The reduction in the amount of CO emission is found with the addition of nanoparticles. Further, it is noted that CO emission decrease with the dosing level of a titanium oxide nanoparticle in both E10 and E15. Among all the prepared fuels, E10TiO$_2$70 shows minimum CO emission, which is nearly 7.6% lower than diesel. This can be due to the presence of nanoparticles.

IV. CONCLUSION

Prime purpose of the present work is the comparative analysis of water diesel emulsion with and without titanium oxide nanoparticles on the basis of performance and emission characteristics of 4 stroke, VCR diesel engine. All the conclusions are drawn on the basis of the experimental results obtained corresponding to full load. The comparison is done on the basis of performance characteristics and emission characteristics.

A. Performance characteristics

- A marginal increase in brake power is observed with the addition of titanium oxide nanoparticles. Among all the prepared fuels, E10TiO$_2$70 shows maximum brake power.
- As compared to other fuels, E10TiO$_2$70 shows higher brake thermal efficiency. Nearly 3.89 % improvement in brake thermal efficiency is observed with E10TiO$_2$70.
- Improvement in brake specific fuel consumption is observed with the addition of TiO$_2$ nanoparticles. The lowest brake specific fuel consumption (0.30 kg/kWh) is observed with E10TiO$_2$70.

B. Emission characteristics

- Increase in NO$_x$ emissions are observed with the addition of TiO$_2$ nanoparticles. As compared to conventional diesel, slightly higher NO$_x$ emissions are observed in the case of E10TiO$_2$70 but this can be neglected due to other positive effects of E10TiO$_2$70.
- Higher HC emission are obtained with E15. However, reduction in HC emission is observed with the addition of TiO$_2$ nanoparticles. Among all the fuels, E10TiO$_2$70 shows minimum HC emission (23 ppm) at CR 18.
- As compared to conventional diesel, higher CO emission is observed in the case of water diesel emulsion. However, the addition of TiO$_2$ nanoparticle results in lower CO emission. E10TiO$_2$70 shows minimum amount of CO emission (71 ppm).

According to above results, E10TiO$_2$70 shows higher performance and lower emissions in comparison to other fuels. Based upon the above results, it is concluded that E10TiO$_2$70 shows promising results on the CI engine performance and emission.

V. SCOPE FOR FUTURE WORK

- Settlement of nanoparticles is the main problem, which limits its use in diesel, biodiesel as well as in water-diesel emulsion. Therefore, there is a need to find better surfactant or techniques, which ensure higher stability of nanoparticles in all the above-mentioned fuels.
- So far, all the experiments have only shown the effect of alternative fuels on enhancement in the performance of engine like brake specific fuel consumption, brake thermal efficiency, and exhaust emissions. However, none of these experiments has given an insight on the long-term effects that these fuels may have on the engine that is piston, cylinder and ring wear, injector nozzle wear and the level of contamination of engine oil taking place.
- Another point of concern is the effect of nanoparticles used in the fuel on exhaust gas and its impact on the environment.
- Recovery of the nanoparticles from exhaust emission is also the major challenge.

All the above-mentioned points are needed to be investigated carefully to deeply understand the influence of nanoparticle blended water diesel emulsion on CI engines. Further, more experiment investigation are needed, to optimize nanoparticle blended water diesel emulsion for commercialization

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