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# Investigation On Innovative Urea-Scr Unit For Ci Engine Emissions Fueled With Neem Oil Methyl Ester

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**Abstract**

A novel type of emission after treatment arrangement consisting DPF, TWC converter by fresh variety of Ad-blue feeding unit with human regulation, distribution part and distribution line to decide extent of improving the competence of existing Urea and SCR arrangement with neat neem oil methyl ester (NOME) as fuel and compared with Diesel-oil. Result indicates ~100% decrease in both CO and HC emissions through retrofit. At the same time observed great reduction in the NOx amount, when compared to traditional arrangement.

**Keywords:** CIE, urea-SCR, DPF, Ad-blue, TWC, emissions, Neem oil, Diesel-oil.

## 1. Introduction

The usage of emission aftertreatment arrangement for CIE is a gauge to execute the regulation necessities. SCR combined by means of $(NH_2)_2CO$ liquids contemplated as hopeful for this enhanced presentation. Especially $(NH_2)_2CO$ filtration through no-fuel fine plus more robustness toward sulfur containing oils.

Europe on-road demos of the $(NH_2)_2CO$-SCR arrangements be performed moreover realistic implementation of the $(NH_2)_2CO$-SCR units worked jointly by transportations used for feeding $(NH_2)_2CO$ liquids. However, there are troubles to be resolved in favor of realistic application of $(NH_2)_2CO$-SCR units. 1$^{st}$ is the little commencement on behalf of NOx decrease and $NH_3$ slip under less emission temperatures and momentary circumstances faced in actual working environs.

The SCR procedure is a fixed model, but still industrially not attested equipment for NOx emission regulation for vehicles. Especially, $NH_3$-SCR attributed by a reductant [$NH_3$] mixed with emission stream is renowned as a moldable solution for movable CIE NOx emissions. Most important dispute in vehicle implementation of $NH_3$-SCR procedure is performance improvement of de-NOx at less emission temperature (i.e. less than 300ºC) as well as aboard storeroom of $(NH_2)_2CO$. Best possible technique available to encourage de-NOx action at less temperature is to guide the reaction to go-through quick SCR pathway.

Most significant point to be contemplated is vaporization of $NH_3$-liquid i.e. Ad-blue solution with emission. For enhancement of surface - chemical reaction and gas – phase - chemical reaction, in the present work it is trialed with evaporation by novel type DEF(or)Adblue -Dosing unit by human regulation, Supply-unit & Supply-Line (copper-tube) wrapped roughly surrounding the exhaust tube to lift the DEF temperature slightly.

The planet is presently taking ecological decay and nonrenewable-fuel exhaustion problems. Numerous evaluations have tried to find out the replacement for nonrenewable-fuel. Burning of bio-diesel in the CIE decreases the different pollutants. Therefore, by utilizing bio-diesel in the present original CI engines will improve the ecological importance by dropping the amount of green-house gasses.

## 1.1. Test fuel plus properties

Neem oil, also known as "margosa oil", is a vegetable oil pressed from the fruits and seeds of the neem (Azadirachta indica), a tree which is indigenous to the Indian subcontinent and has been introduced to many other areas in the tropics. It is the most important of the commercially available products of neem and is used for organic farming and medicines. Properties of test fuel are demonstrated in Table 1.

Table 1 Properties of test fuel

| PROPERTIES | DIESEL | NOME |
|---|---|---|
| Specific gravity | 0.830 | 0.860 |
| Kinematic Viscosity @40$^0$ C (c St) | 3.72 | 4.5 |
| Calorific Value (kJ/kg) | 42500 | 38500 |
| Flash point in ($^0$C) | 62 | 152 |
| Fire point in ($^0$C) | 64 | 180 |
| Cetane No | 48 | 51 |

## 1.2. DPF

The channel encloses usually $Al_2O_3$ wash cover carried on honey-comb profile earthenware block as revealed in Fig.1.

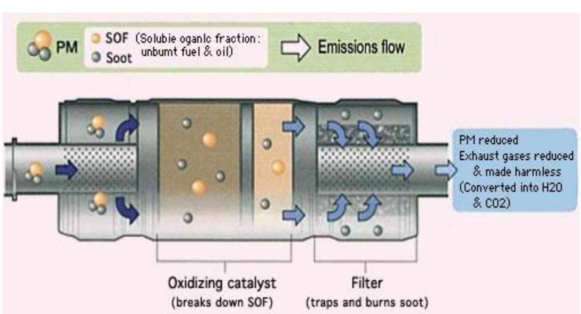


**Fig. 1 DPF**

## 1.3. TWC

This channel gets its title since regulating 3 chief pollutants in an exhaust viz., NOx, VOC's plus CO. The channel normally holds $Al_2O_3$ wash cover carried on honey-comb profile earthenware block as depicted in Fig.2. Expensive materials were layered over alumina. Dynamic portion of medium is additionally separated as oxidation & reduction spots. Combination of platinum-rhodium elements perform as dynamic places toward succeed reduction responses, whereas platinum-palladium performs as dynamic elements for oxidation responses.

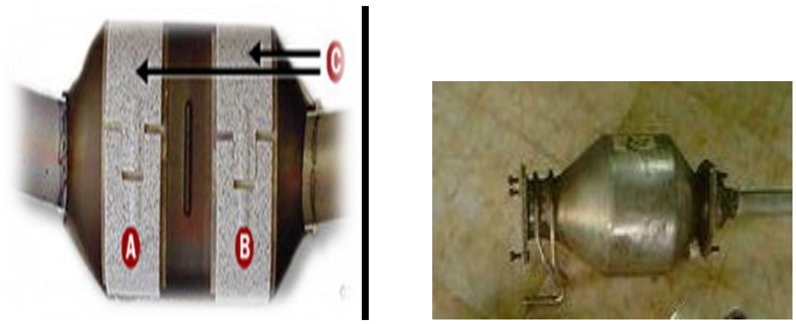


**Fig. 2 TWC Converter**

A: Reduction Catalyst

B: Oxidation Catalyst

C: Honeycomb Ceramic Structure

Reduction of nitrogen oxides to nitrogen and oxygen:

$2NO_x \rightarrow xO_2 + N_2$

Oxidation of carbon monoxide to carbon dioxide:

$2CO + O_2 \rightarrow 2CO_2$

Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water:

$C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$

## 1.4. Adblue / DEF

DEF is a chemical mixture prepared by 67.5% pure-$H_2O$ & 32.5% granular-$(NH_2)_2CO$. DEF acts as transportation means for $NH_3$ required for reducing NOx from vehicle-engine to $N_2$, $H_2O$ & $CO_2$.

Urea Decomposition Reaction (when DEF is introduced into the hot stream of exhaust gas water evaporates and urea thermally decomposes to form $NH_3$ and $CO_2$)

$(NH_2)_2CO \rightarrow NH_3 + HNCO$ further reaction $HNCO + H_2O \rightarrow CO_2 + NH_3$

Overall reaction for Urea Decomposition

$(NH_2)_2CO + H_2O \rightarrow 2\ NH_3 + CO_2$

Ammonia Reaction (in the presence of oxygen and a catalyst)

$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$ or $8\ NH_3 + 6\ NO_2 + O_2 \rightarrow 7\ N_2 + 12\ H_2O$

## 2. Literature Review

Resitoglu [1] found that the major considerable contaminants formed in biodiesel-fuelled CIE are PM, NOx, HC, and CO, among this NOx constitutes higher than 50%, chased by PM.

Hoekman et al. [1-2] worked on bio-diesel and bio-diesel mixtures are used in CIE, number of examiners confirmed that pollutants CO, HC and PM have been significantly decreased whereas the NOx observed to be raised.

Sindhu [3] researched with split inoculation; a little quantity of oil is grabbed in the initial pulsation is to warningly decrease NOx suitable to the pre-mixed burning. Split inoculations were found to be efficient in NOx decrease. In current years, selective catalytic reduction, an exhaust aftertreatment method observed to be successful in NOx decrease, even though its passing in present generator necessitates exhaust alterations which is not economical. LTC methodologies are implemented in contemporary CIE to decrease NOx and PM by Praveena [4].

Yuvarajan et al. [5-7] experimented on bio-diesel and its diverse mixtures utilized in CIE guide to rise in NOx and BSFC than unadulterated diesel unsettled to enhanced $O_2$ percentage in mixtures.

Relatively, bio-diesel oils present a decrease of dangerous pollutants such as PM, CO, & HC; conversely, it creates higher NOx was proved by Janaun et al. [8-9] The major dangerous NOx influences the surroundings via acid-rainfall, individual illness, etc. Further, Latha et al. [10-11] investigated on CO and NOx are chief pollutants in the development of troposphere-$O_3$.

Bio-diesel with 60 to 65% of $H_2O$ mixed with oil can decrease upto 50percent NOx, more WI ($H_2O$-injection) percentage be capable of decrease more NOx under different load circumstances identified by Tauzia [12].

Hountalas [13] deliberated 2 techniques of NOx decrease methods which are $H_2O$-injection & $H_2O$-suspension in DI-CIE. Results revealed that, $H_2O$-insertion is improved compared to $H_2O$-blend; conversely, above two procedures were competent as contrasted to ordinary CIE function.

Further, Sahin [14] discovered emulsification procedure leads to rise in the HC & CO due to the decrease in burning cavity hotness which can afterward influence the burning competence. Basha [15] examined the task of nano-additive utilized in emulsified bio-diesel in CIE. They explored on emulsified bio-diesel of 83% Jatropha bio-diesel +15% $H_2O$ + 2% surfactant. Depending on testing in a 1-cylinder engine, it is found that the NOx decreases by 21%, the PM decreases by 15% though the HC rises by 46%, BTE improved by 2.5%, while BSFC decreased by 2.6%.

Few of the investigators Swaminathan et al. [16-17] implemented concurrent methodologies to get improved solutions such as fuel-additive with EGR and ITR with EGR.

Related to the above situation, Saravanan [18] researched the joint influence of EGR, ITR and injection-pressure on RME bio-diesel fuelled 1-cylinder CIE. They observed that, the minimal grouping of engine factors by utilzing Taguchi-technique decreases the Fig. of investigational effort and found that NOx decreases with slight reimbursement on the effectiveness and other contaminations.

Manuscript Assessed on NOx decreasing practices such as WI, $H_2O$-emulsification, injection-timing retardation and concurrent tools and its influence on different working factors conceded-out in bio-diesel fuelled CIE by Prabhu Appavu [19].

The conceptual model of Urea Dosing System Denoxtronic 3.1 developed by Bosch [20] has been in succession production at numerous OEMs since mid 2008. Implementation of the Denoxtronic 3.1 previously facilitates fulfillment with Euro 6 and Tier2 Bin5 restrictions & is the base for most of the recent work in the area. Probable applications: The

Denoxtronic 3.1 is principally designed for utilize in passenger cars and in the light-duty sector. Additionally probable implementations present in the off-highway section for engines in the range 56…100 kW. {SCR Technology for NOx Reduction: Series knowledge and State of Development Manuel Hesser, Hartmut Lüders, Ruben-Sebastian Henning Robert Bosch Corporation / Robert Bosch GmbH}

From above survey, different practices implemented in CIE such as WI, $H_2O$-emulsification, engine alteration and concurrent methodology to decrese NOx were vitally evaluated. Also discussed the consequences of emissions, performance and burning features by different NOx decreasing methodologies in bio-diesel & fuel-additive mixtures powered CIE.

Jayashri N. Nair [21] studied about emission and performance characteristics on CIE with blends of Neem oil as biodiesel. Biodiesel is prepared from Neem oil by transesterification process followed by adding 1% v/v $H_2SO_4$. The tests were performed with B10, B20, B30 blends on a one cylinder, 4-stroke, CIE. The result shows lower emissions and higher performance for B10 than the other blends and diesel. The brake thermal efficiency is higher than the diesel and CO, HC and $NO_X$ emissions were 23%, 8.5%, and 22% lesser than that of diesel.

Prabhu L [22] investigates the performance and emission characteristics of a single cylinder diesel engine using titanium oxide ($TiO_2$) nano particles as additive in neat diesel and diesel-biodiesel blends. A 250ppm of titanium oxide nano-particle is blended with 20% biodiesel-diesel blend (B20). These blends are subjected to high speed blending followed by ultrasonic bath stabilization that improves the stability of the blends. The experiments were conducted in a diesel engine to study the performance and emission characteristics of a diesel engine with diesel, 250ppm $TiO_2$ with B20 biodiesel blend at different load conditions. The results showed that the brake thermal efficiency was increased and the brake specific diesel-biodiesel was decreased by 12% for 250ppm nano particle added with B20 blends at full load. The carbon monoxide (CO), hydrocarbon (HC) and smoke emissions were decreased while the NO emissions were increased marginally due to peak combustion temperature prevailing in the combustion chamber at full load conditions.

Sivasubramanian Rathinam [23] focuses on the effect of particle size of cerium oxide ($CeO_2$) nanoparticle on the emissions characteristics of four-stroke, single cylinder water cooled diesel engine fueled with neat neem biodiesel (NBD100). Neem oil is transesterified into biodiesel and employed in this work. Cerium oxide as an additive in various particle-size of 10 nm and 20nm is included to NBD100 and termed as NBDCe$O_2$10 and NBDCe$O_2$20. The experimental result proved that all the chemical and physical properties of fuels are in sequence with ASTM standards. The CO and HC emissions are 4.3% and 4.7% lower for NBD100 than diesel at 3.5 bar BMEP. $CeO_2$ nanoparticle further reduces CO and HC emissions 4.2% and 3.6% correspondingly for NBDCe$O_2$20 than NBD100. The degree of $NO_X$ emission in NBD100 is 5.6% higher at 3.5 bar BMEP. When compared to NBD100, tailpipe NOx emission was found to be 2.7% and 3.6% lower when fueled with NBDCe$O_2$10 and NBDCe$O_2$20. In addition, the tailpipe smoke emission was found to be 1.7% lower when fueled with NBD100.

Devaraj Rangabashiam [24] investigates the effect of two oxygenated additives, DMC (Dimethyl-carbonate) and Pentanol (n-P) on ignition patterns of biodiesel/diesel blends in the diesel engine. DMC and Pentanol were mixed at 10% volume with the equivalent blends of neem-biodiesel and diesel. Blending additives and biodiesel to diesel was carried out without any surfactant and found no phase-separation and remained stable. Performance results revealed a signifcant improvement in the performance pattern of biodiesel/diesel blends. BSFC is lowered by '0.4 and 0.5 g/kW with 0.3 and 0.6% increase in BTE was observed by blending DMC and Pentanol to base fuel (NBD50D50) respectively. Adding 10% Volume of Pentanol and DMC lowers the CO emission of NBD50D50 by 4.9% and 7.4% at all loads. In addition, 3.1% and 4.7% reduction in HC emissions were observed by blending 10% of DMC and Pentanol to base fuel in that order. Peak pressure of base fuel is increased by 2.3 and 3.1 bar by adding DMC and pentanol, respectively. Further, 3.9 and 2.1 J/CA of HRR is improved by adding DMC and pentanol to NBD50D50 due to its improved properties.

B. Sachuthananthan [25] identified that the use of biodiesel in diesel engines leads to the reduction of tail pipe emissions; But, several researchers portray that the use of biodiesel produces more NOx pollution than diesel-fuelled engines, which is an hindrance for the scope of biodiesel usage. In this work, an experimental investigation of the combined effect of antioxidant additive added in the fuel as a fuel modification technique and SCR (selective catalytic reduction) as after a treatment technique on NOx reduction in a neem biodiesel-powered compression ignition engine has been conducted. Results show that the antioxidant additive combined with the SCR technique reduces the NOx emission significantly by 82% and there was a slight increase in UBHC and CO emission due to the addition of oxidation-suppressing additives with neem biodiesel and aqueous urea solution injection at the exhaust without a major drop in BTE and fuel consumption.

C. Srinidhi [26] provides a comparative experimental survey of using exhaust gas recirculation and nanoparticle in biodiesel blends. The experimental work was carried on a DI-CI engine. Neem biodiesel blend of 25% (NB25) by volume was used as a base fuel with petro Diesel. Biodiesel blend is used with EGR at different Injection opening pressures. Also Nickel Oxide nanoparticle blended Neem biodiesel is used as fuel at different EGR rates. The performance results of using nanoparticles induced NB25 blend over EGR proves to be better. A total rise of 17% brake thermal efficiency was observed with nanoparticle as compared to EGR method. Also EGR method phenomenally results in controlling oxides of nitrogen emission but quite higher levels of unburnt HC, CO and CO2 were observed.

Karthickeyan Viswanathan [27] presents, non-edible seed oil namely raw neem oil was converted into biodiesel using transesterification process. In the experimentation, two biodiesel blends were prepared namely B25 (25% neem oil methyl ester with 75% of diesel) and B50 (50% neem oil methyl ester with 50% diesel). Urea-based selective catalytic reduction (SCR) technique with catalytic converter (CC) was fixed in the exhaust tail pipe of the engine for the reduction of engine exhaust emissions. Initially, the engine was operated with diesel as a working fluid and followed by refilling of biodiesel blends B25 and B50 to obtain the baseline readings without SCR and CC. Then, the same procedure was repeated with SCR and CC technique for emission reduction measurement in diesel, B25 and B50 sample. The experimental results revealed that the B25 blend showed higher break thermal efficiency (BTE) and exhaust gas temperature (EGT) with lower break-specific fuel consumption (BSFC) than B50 blend at all loads. On comparing with biodiesel blends, diesel experiences increased BTE of 31.9% with reduced BSFC of 0.29 kg/kWh at full load. A notable emission reduction was noticed for all test fuels in SCR and CC setup. At full load, B25 showed lower carbon monoxide (CO) of 0.09% volume, hydrocarbon (HC) of 24 ppm, and smoke of 14 HSU and oxides of nitrogen (NOx) of 735 ppm than diesel and B50 in SCR and CC setup. On the whole, the engine with SCR and CC setup showed better performance and emission characteristics than standard engine operation.

From the above literature following observations can be drafted

i. NOx can be reduced up to 37percent to 50percent by WI practice in bio-diesel engines and also CIE with a little rise in BSFC & CO.
ii. Also found that $H_2O$-biodiesel-suspension decreases NOx around 10percent to 60percent contrast to traditional oil. Conversely, numerous examiners determined emulsification raises CO and HC by 16 to 94% and 45 to 55% respectively.

iii. Injection time retardation decreases NOx up to 8 to 40.5% than ordinary injection timing however raises other pollutants. Although, it also simultaneously decreases BTE & raises BSFC.

iv. Parallel tools have many benefits compared to individual due to numerous methodologies similar to additive-EGR, ITR-EGR, etc. It is determined that NOx reduced up to 95%; conversely, it raises PM, HC, and CO considerably.

v. It was observed that very scanty works were carried out in the area of SCR and CC-operated diesel engine.

In the present study, raw neem oil was converted into neem oil methyl ester using transesterification process. Aqueous urea-based DPF+TWC+DEF set was fabricated and installed in the exhaust tail pipe. To obtain baseline readings, the engine was filled with diesel fuel with DPF+TWC+DEF setup, DPF+TWC setup and without DPF+TWC+DEF setup. Then the engine was operated with NOME under similar above different arrangements of DPF+TWC+DEF setup. The emission characteristics of diesel and NOME were obtained with DPF+TWC+DEF setup, DPF+TWC setup and without DPF+TWC+DEF setup, and compared.

**3. Details of Experimentation**

## 3.1. Test rig arrangements

The test-rig comprise of 1-cylinder 4-stroke DI-CIE with 80mm bore, 110mm stroke length, rated speed of 1500rpm, 5BHP/3.7KW rated power and water cooled engine.

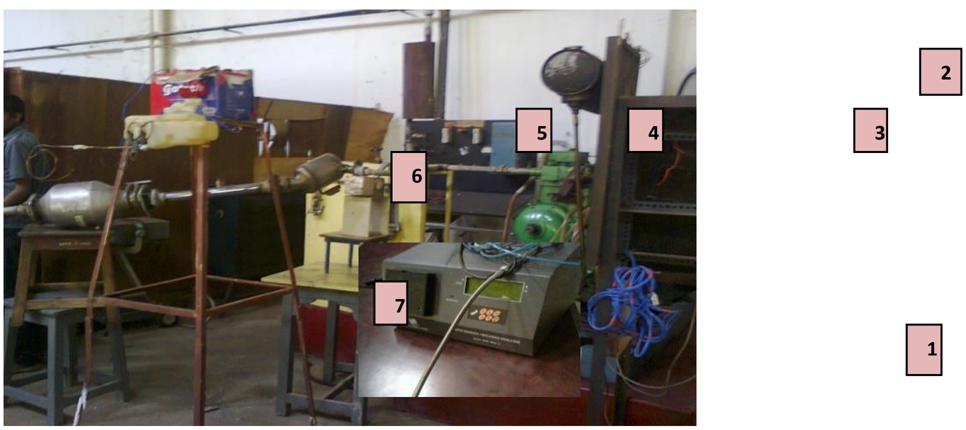


**Fig. 3Experimental Setup**

## 3.2. Major components (represented in the above Fig. 3)

1. kirloskar-CIE
2. diesel tank
3. control panel
4. DPF
5. DEF tank with supply module & battery
6. TWC
7. Multi-gas analyzer

## 3.3. Engine Specifications

- Engine Manufacturer : KIRLOSKAR (DC Shunt Dynamometer)
- Type : 1-cyl 4-stroke DI CI engine
- Aspiration : Naturally Aspirated
- Bore : 80 mm
- Stroke : 110 mm
- Rated Speed : 1500 rpm
- Cooling System : Water Cooled
- Rated Power : 5BHP/ 3.7 KW

## 3.4. Novel DEF arrangement:

| | |
|---|---|
| Feeding amount | 162g/h @ 1.5bar |
| Nozzle Type, Material & diameter | 1- Hole, Brass & 400 µm (Sauter Mean Diameter) |
| Environmental operation settings | |
| Distribution unit : | -30…..70$^0$C |
| Dosing Module : | -30…..140$^0$C |
| Operating Voltage | 12 V |
| Distribution line length between Distribution unit & Feeding unit | 3805 mm |
| Distribution Line Material, Cross-section | Cu, Circular tube |
| Adblue-Tank Material | Plastic |

### 4. Outcomes and Deliberation

Tests are performed while CIE powered by NOME and Diesel separately. The trial enclosed a variety of loadings from zero to 2kW. The pollutant qualities of CIE were experiential in amount of CO, HC, NOx, and $CO_2$. The consequences got for DPF+TWC converter +DEF unit coupled at tail pipe of exhaust were contrasted with DPF+TWC converter unit and without connecting any of the above mentioned units.

## 4.1. Carbon Monoxide (CO)

Figure 4.1 shows the variations in the carbon monoxide (CO) for all the three modes of operation fuelled by NOME and Diesel separately. The CO is lesser when contrasted to the BS-IV standards for chosen engine at different loads for different modes. The CO rises proportionally with increasing load up to 2kW without linking any unit. After connecting DPF+TWC and with DPF+TWC+DEF units the CO remain constant with 0.000% values. The lower CO emission of NOME compared to diesel is likely due to oxygen content inherently present in the NOME which helps in the more complete oxidation of fuel. Further it can be seen that volume of CO initially decrease but increase at full load indicating better burning conditions.

CO amount is zero for DPF+TWC and DPF+TWC+DEF unit linked, when contrasted without connecting any unit to exhaust pipe for both Diesel and NOME. This is due to oxidation of CO in TWC system. The CO is lesser when contrasted to BS-IV standards for chosen test-rig under every working load by arrangement fitted.

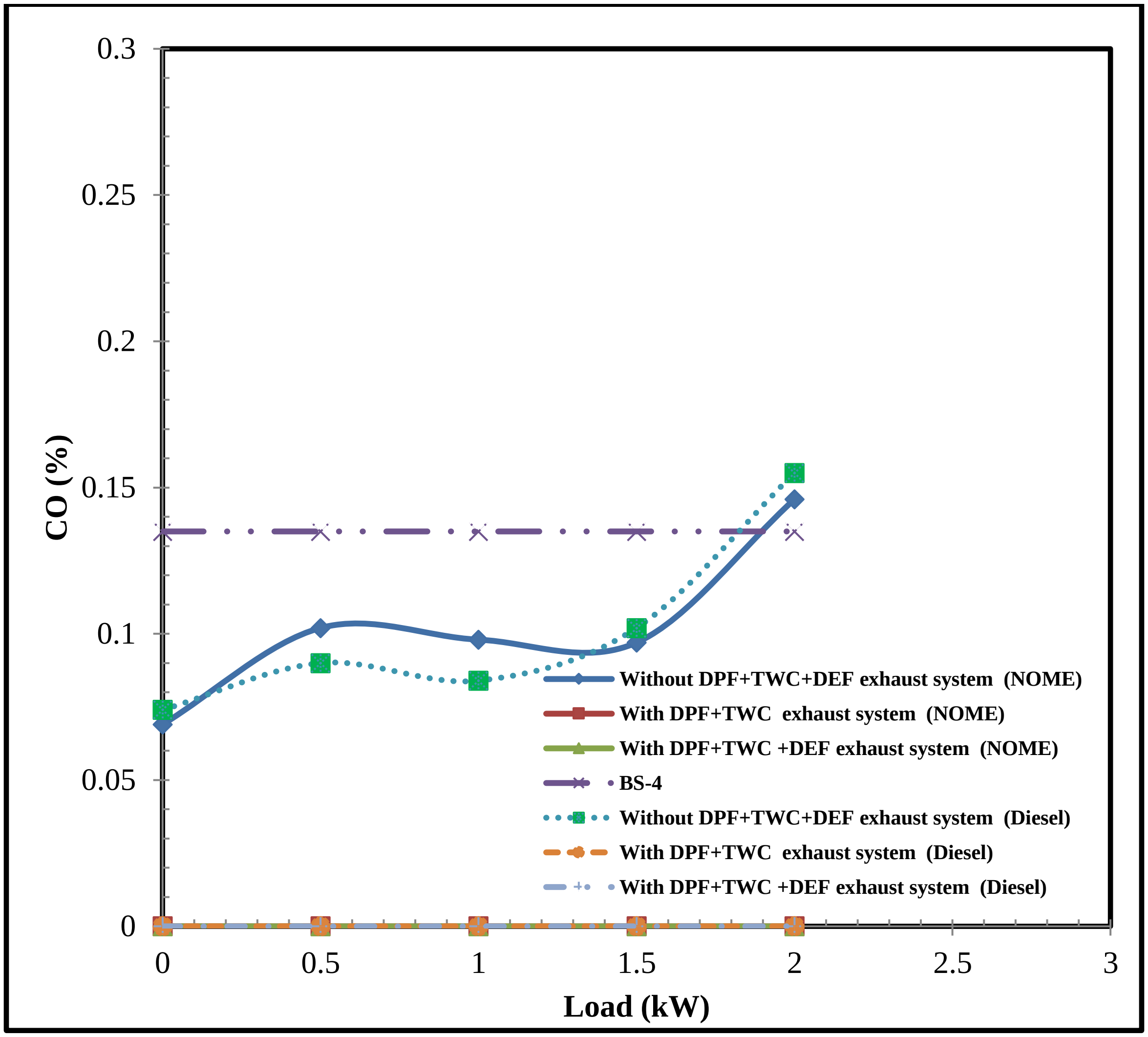


**Fig. 4.1Variations in the carbon monoxide (CO)**

## 4.2. Hydrocarbons (HC)

The result for the variations in the unburnt hydrocarbon (HC) is presented in the Figure 4.2 for all the three modes of operation by using NOME and Diesel separately. HC is higher while contrasted to BS-IV standards for chosen CIE at higher loadings without linking any unit. After connecting DPF+TWC and DPF+TWC +DEF units the HC variation is constant with 0.000ppm values for both NOME and Diesel. The emissions of unburnt hydrocarbon for NOME exhaust lower than that of diesel fuel due to the increased gas temperature and higher cetane number of NOME could be responsible for this decrease. Higher temperature of burnt gases in NOME fuel helps in preventing condensation of higher hydrocarbon reducing unburnt HC. The higher cetane number of NOME results decrease in HC emission due to shorter ignition delay.

Amount of HC is '0' for DPF + TWC and DPF+TWC+DEF unit linked, when contrasted without connecting any unit at the tail pipe for both Diesel and NOME. This is because of oxidation of HC with TWC system. The HC is lesser when contrasted to the BS-IV standards for chosen test-rig under every working load with retrofit arranged.

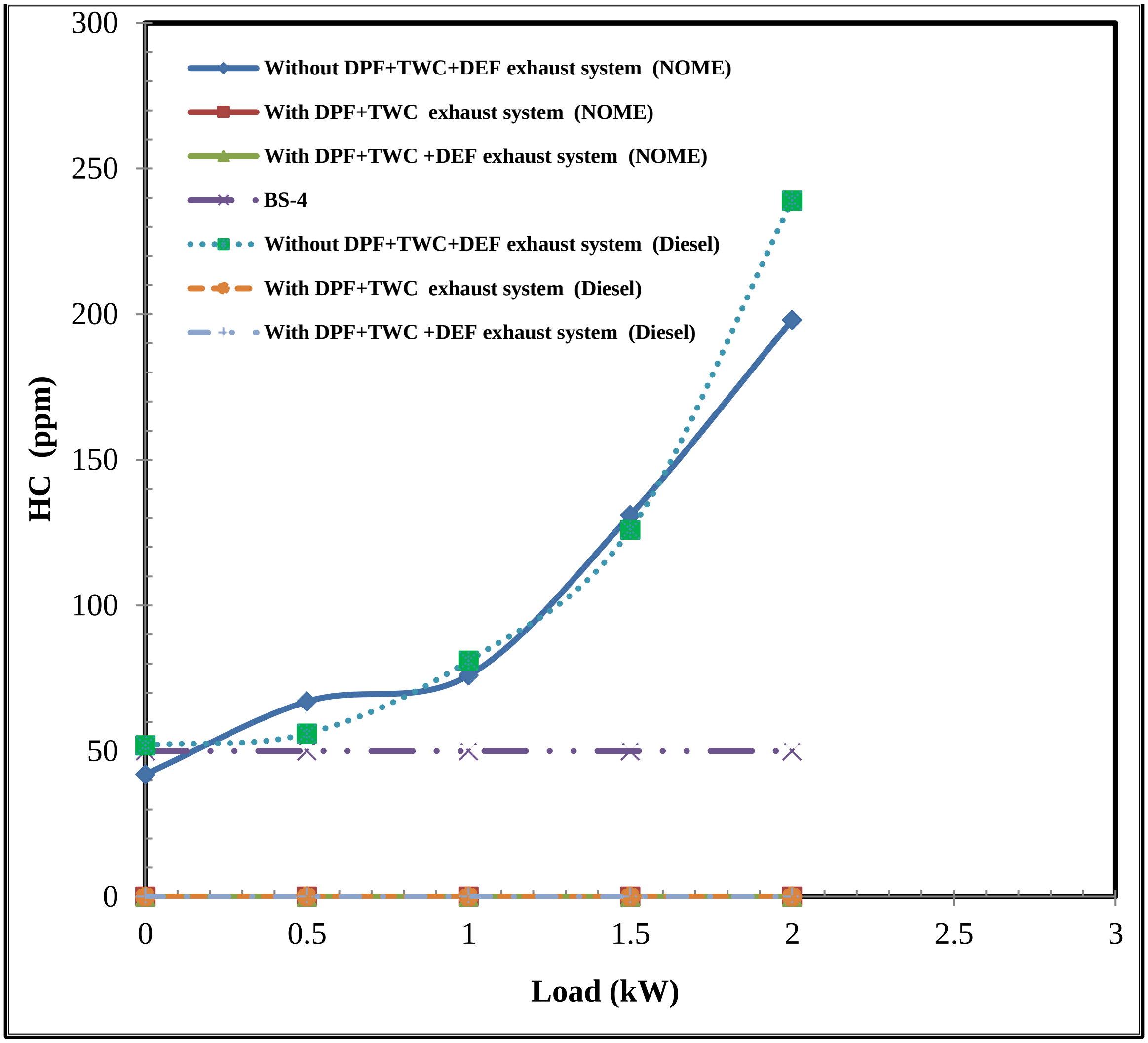


Fig. 4.2Variations in the unburnt hydrocarbon (HC)

### 4.3. Nitrogen Oxides (NOx)

The NOx values as ppm for different blends of diesel and NOME in exhaust emission are plotted as function of load. From these figure 4.3 it can be seen that the fueling NOME increase NOx emission slightly compared with that of diesel for all the three modes of operation. These could be attributed to

- Increase exhaust gas temperature due to lower heat transfer and the fact that biodiesel has some oxygen content in it which facilitates NOx formation.
- Higher cetane number of NOME shortens ignition delay advancing combustion conducive for NOx formation.

Nitrogen oxides / dioxides (NOx) contamination is low for both DPF+TWC+DEF unit and DPF+TWC attached, when differentiated without any unit fitted. This results because of reduction of NOx into nitrogen, water and carbon-dioxide. The NOx presence is minor when contrasted to the BS-IV standards for chosen test-rig under every working load with whole arrangement.

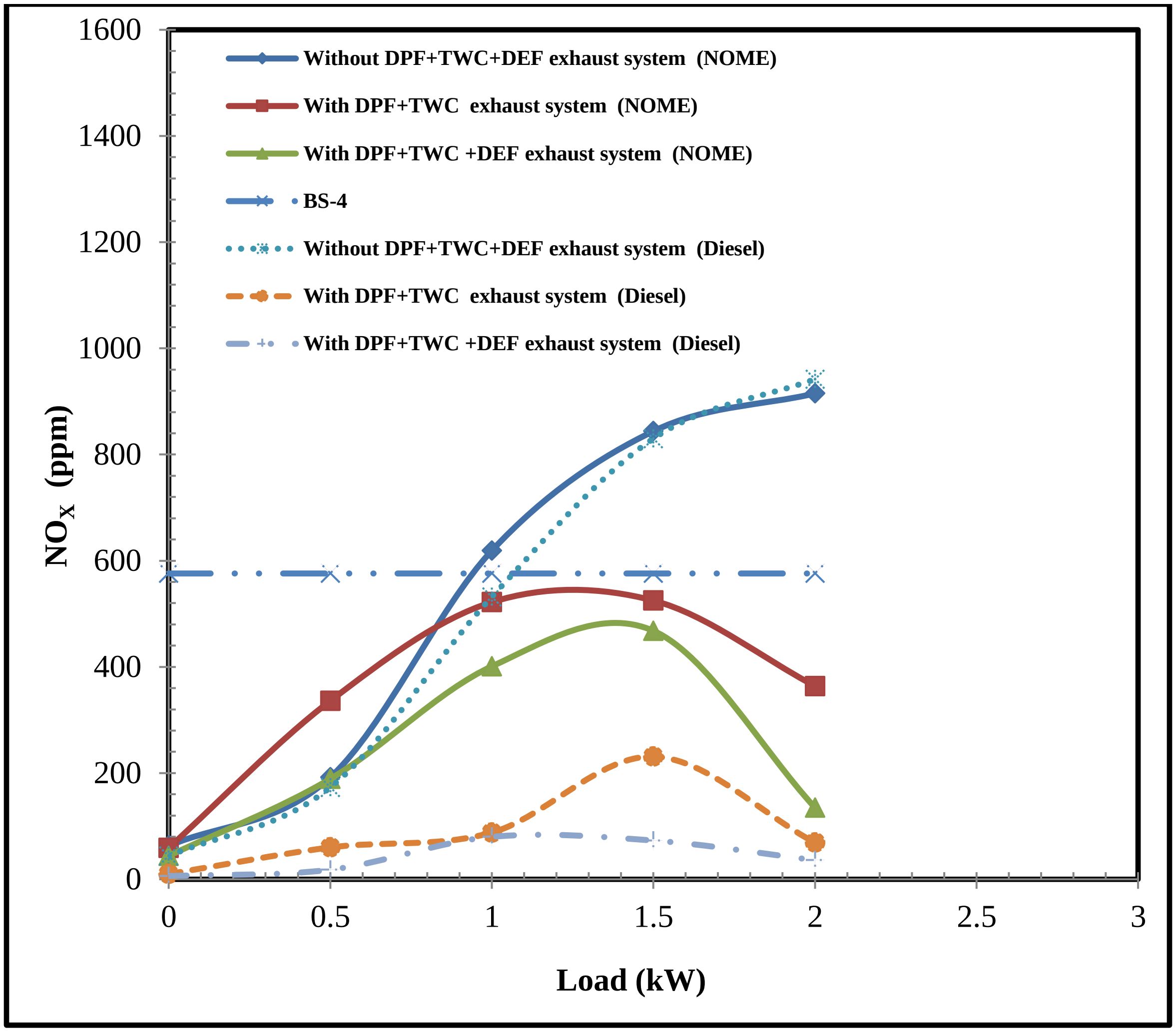


**Fig. 4.3Variations in the nitrogen oxides (NOx)**

## 4.4. Carbon Dioxide ($CO_2$):

The result for the variations in the carbon dioxide ($CO_2$) is presented in the Figure 4.4, for all the three modes of operation for both Diesel and NOME. The $CO_2$ increase proportionally with respect to load up to 2kW. This shows the presence of minimal value of $CO_2$ at 0kW for both oils under all modes. From Figure 4.4 it is obviously observed that $CO_2$ is highest for NOME compared to Diesel-oil for all modes. These results due to

- Higher exhaust gas temperature leads to complete burning of fuel with increase in the load.
- When using NOME which is having lower compressibility compared to diesel thus lower compressibility and higher speed of sound in NOME shorten ignition delay permitting can combustion conditions conducive for complete combustion of oil.

As a universal law, more the $CO_2$ amount, higher capable the engine is working.

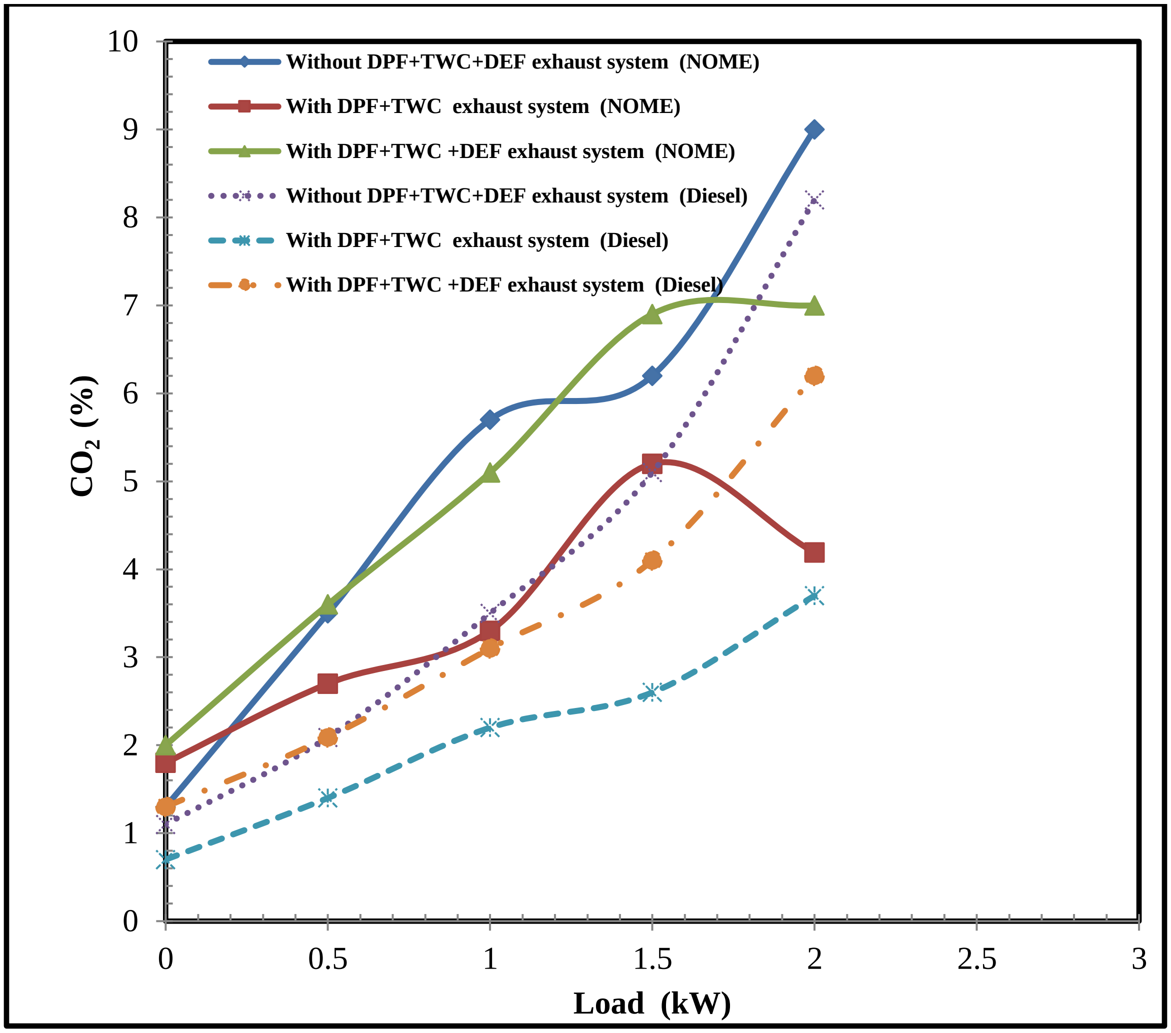


**Fig. 4.4 Variations in the carbon dioxide ($CO_2$)**

## 5. Conclusions

Depending on the values got from the trials conducted, subsequent judgments may be summarized as follows:

* NOME can be directly used in diesel engines without any modifications with new unit.

* Compared with conventional diesel, exhaust emissions of CO and HC are reduced while NOx emissions are increased with NOME for different modes.

* The availability of abundant resources and environmental friendly emissions are recognized as strength of NOME leading it to potential candidate as alternative fuel for future CIE.

* From the investigation done it is clearly found that DPF+TWC+DEF unit is best-appropriate alternate for CIE exhaust aftertreatment arrangement as this unit generates smaller/no emissions than traditional setup under every load situation.

**Symbols/notations**

BSFC Break specific fuel consumption

| | |
|---|---|
| BTE | Break thermal efficiency |
| CI | Compression ignition |
| CIE | Compression ignition engine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| DI | Direct injection |
| DOC | Diesel oxidation catalyst |
| DEF | Diesel exhaust fluid |
| DPF | Diesel particulate filter |
| EGR | Exhaust gas recirculation |
| HC | Hydro carbons |
| $H_2O$ | Water |
| ITR | Injection timing retardation |
| kW | Kilo watt |
| LTC | Low temperature combustion |
| $N_2$ | Nitrogen |
| $NH_3$ | Ammonia |
| NOME | Neem Oil Methyl Ester |
| NOx | Nitrogen oxides |
| $O_2$ | Oxygen |
| OEM | Original equipment manufacturer |
| PM | Particulate matter |
| RME | Rapeseed methyl ester |
| SCR | Selective catalytic reduction |
| TWC | Three way catalyst |
| VOCs | Volatile organic compounds |
| WI | Water injection |
| % | Percentage |

**Conflicts of Interest**

This is to assure that there is no any type of conflict of interest in publication of original research work done.

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