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Experimental Exploration of Novel Exhaust After-treatment System for CI Engine Emissions

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Abstract

A novel type of emission aftertreatment arrangement consisting DPF, TWC converter (in substitution of SCR & Oxidation catalyst) with fresh variety of Ad-blue feeding unit with human regulation, distribution part and distribution row approach to decide extent of improving the competence of existing Urea and SCR arrangement. Result indicates ~100% decrease in both CO and HC emissions through retrofit. Simultaneously observed 93% fall in the NOx, when compared to traditional arrangement (i.e, without any system mentioned above).

Keywords: CIE, urea-SCR, DPF, Ad-blue, emissions, TWC.

1. Introduction

The usage of emission aftertreatment arrangement for CIE is a gauge to execute the regulation necessities. SCR combined with urea liquids are contemplate to be hopeful for this enhanced performance. Especially urea filtration with no fuel fine and more robustness to sulfur containing oils.

Europe, on-road demos of the Urea-SCR arrangements are performed and realistic implementation of the Urea-SCR units worked jointly with the transportations for feeding urea liquids. However, there are troubles however to be resolved for realistic application of Urea-SCR units. The 1st is the little commencement for 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 emission. One of the most important disputes in the vehicle implementation of the NH_3-SCR procedure is the improvement of the de-NOx performance at less emission temperature below 300ºC and on-board storeroom of Urea. One of the possible techniques to encourage de-NOx action at less temperature is to guide the effect to pass-through the quick SCR pathway.

One of the significant points to be contemplated is vaporization of NH_3-liquid i.e. Ad-blue solution with emission. For the enhancement of surface-reaction and gas-phase-reaction, in the present work it is trialed with evaporation by novel type of DEF/Adblue-Dosing unit with human regulation, Supply unit & Supply Line (made of copper material) wrapped roughly surrounding the exhaust tube to raise the temperature of DEF.

The current examination deals with research on CIE test-rig inorder to decide the exhaust gas emissions at the end of tail pipe at different loads by arranging the setup proposed.

1.1. Diesel Particulate Filter

The catalyst encloses usually an alumina wash coat carried on a honeycomb shape ceramic brick as shown in Fig. 1.

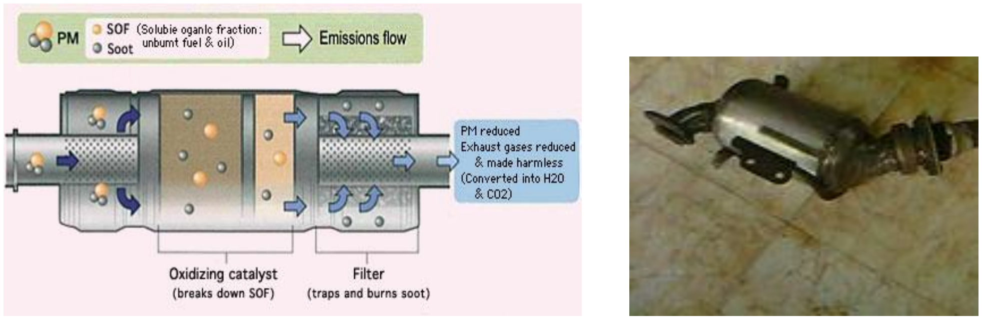

Fig.1DPF

1.2. Three Way Catalytic (TWC) Converter

This catalyst gets its name from regulating the 3 chief emissions in an engine that are NOx, VOCs and CO. The catalyst normally holds an alumina wash coat carried on a honeycomb shape ceramic brick as shown in Fig. 2. Expensive metals are layered onto the alumina. The dynamic portion of the catalyst is additionally separated into oxidation and the reduction spots. The platinum/rhodium elements perform as the dynamic places to succeed reduction reactions, while platinum/palladium performs as the dynamic elements for oxidation reactions.

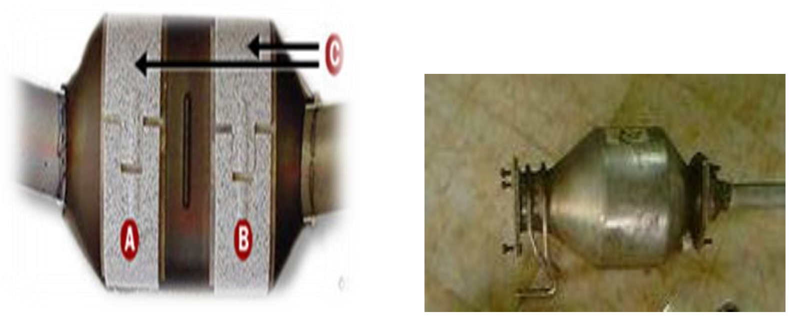

Fig. 2TWC Converter

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:

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

1.3. Adblue / DEF

DEF is a chemical mixture prepared by 67.5% pure-H_2O and 32.5% granular-urea. This is the transportation means for the NH_3 required to reduce NOx emissions from vehicle-engine into N_2, H_2O and 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 the emissions of CO, HC and PM have been significantly decreased while the NOx observed to be raised.

Sindhu [3] researched with in split-injection, a little quantity of oil is grabbed in the initial pulsation is to warningly decrease NOx due to the pre-mixed burning. Split-injections are found to be efficient in NOx decrease. In current years, SCR, an after-treatment method is observed to be successful in NOx decrease, although its passing in present engines 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 emissions such as CO, HC and PM; conversely, it creates more 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 NOx and CO are chief emissions in the development of tropospheric-ozone.

Biodiesel with 60–65% of H_2O in the fuel can decrease upto 50% NOx, more WI (H2O-injection) percentage can 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-emulsion in DI CIE. They have concluded that, H_2O-injection is improved than H_2O-emulsion; conversely, both are competent when contrasted to ordinary CIE operation.

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.

From the above literature following observations are made

i. NOx can be reduced up to 37–50% by WI practice in bio-diesel engines as well as CIE with a little rise in BSFC and CO.
ii. It is found that H_2O-biodiesel-emulsification decreases the NOx around 10–60% contrast to traditional oil. Conversely, numerous examiners determined emulsification raises CO and HC by 16–94% and 45–55% respectively.
iii. Injection-timing retardation decreases the NOx up to 8–40.5% than the ordinary injection-timing but raises the HC, CO and PM emissions. But, it also simultaneously decreases BTE and 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 upto 95%; conversely, it raises HC, CO and PM considerably.

In-order to overcome above all issues related to emissions without affecting performance and combustion characteristics the following experimentation was carried out.

3. Experimental details

3.1. Experimental Systems and Description

The experimental set up consists of single cylinder 4-stroke DI CI engine with 80mm bore-diameter, 110mm stroke length, rated speed of 1500rpm, 5BHP/3.7 KW rated power and water cooled engine.

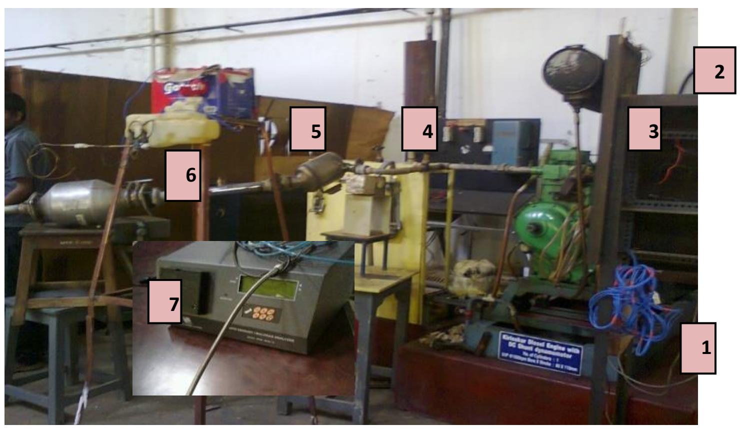

Fig. 3Experimental Setup

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. Technical Features of Novel DEF - system:

Feeding amount	163 g/h @1.5 bar
Nozzle Type, Material & Atomization	1- Hole, Brass & 400 µm (Sauter Mean Diameter)
Environmental operation settings Distribution unit : Dosing Module :	 -30…..70^{0}C -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. Results and Discussions

Tests were performed when the engine was powered with pure-diesel. The trial covered a range of loads from zero to 2kW. The emission qualities of the engine were experiential in terms of amount of CO, HC, O_2, NOx and CO_2. The consequences got for DPF+TWC converter +DEF unit coupled at the 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)

The result for the variations in the carbon monoxide (CO) is presented in the Fig. 4.1, for all the three modes of operation. The CO is lesser when contrasted to the BS-IV & Euro VI standards for chosen engine at different loads. The CO rises with increasing load up to 0.5kW and then fall upto 1kW, beyond that CO increase with loading. This designates the presence of minimal value of CO at 0kW. From Fig. 4.1 it can be evidently observed that CO is high for 2kW without linking any unit. After connecting DPF+TWC and with DPF+TWC+DEF units the CO variation is constant with 0.000 (%) values.

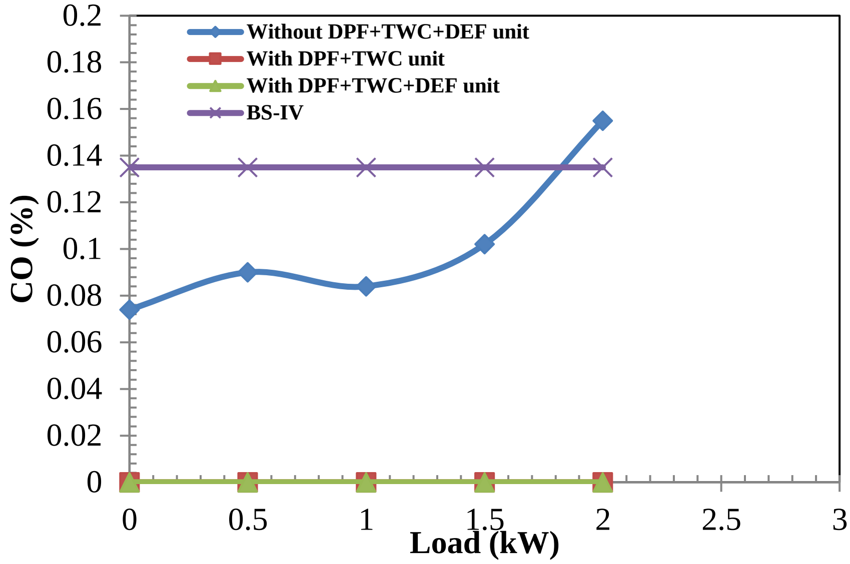

Fig. 4.1Variations in the carbon monoxide (CO)

4.2. Oxygen (O_2)

The result for the variations in the oxygen (O_2) is presented in the Fig. 4.2, for all the three modes of operation. The O_2 decrease proportionally with respect to rise in the load up to 2kW.This depicts the presence of minimal value of O_2 at 0kW. From Fig. 4.2 it is evidently observed that O_2 is least for 2kW without linking any unit. After connecting DPF+TWC converter, the O_2 decrease proportionally with respect to load up to 2kW. But the values of O_2 were more when compared to above mode of operation. When DPF+TWC+DEF unit is linked the O_2 decrease proportionally with respect to load up to 2kW but the values are less compared to second mode of operation.

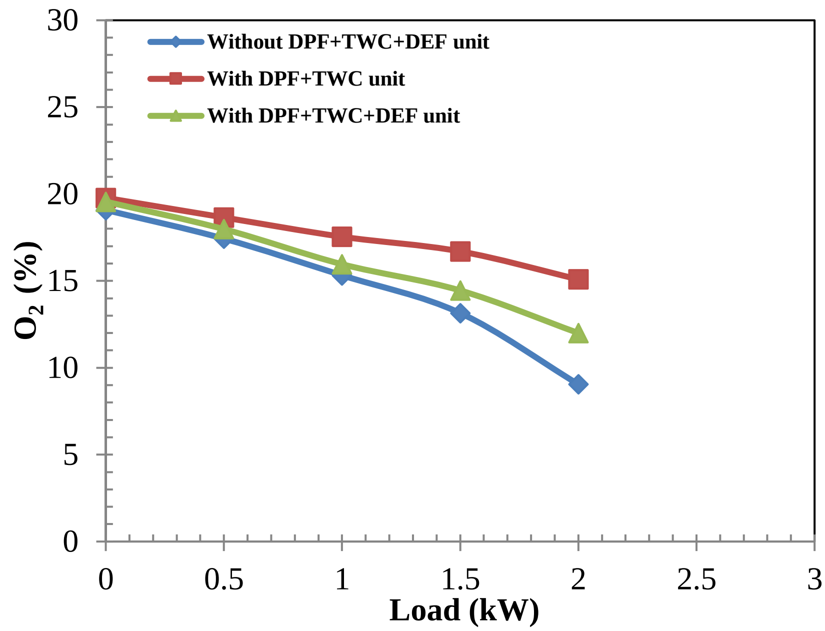

Fig. 4.2Variations in the oxygen (O_2)

4.3. Hydrocarbons (HC)

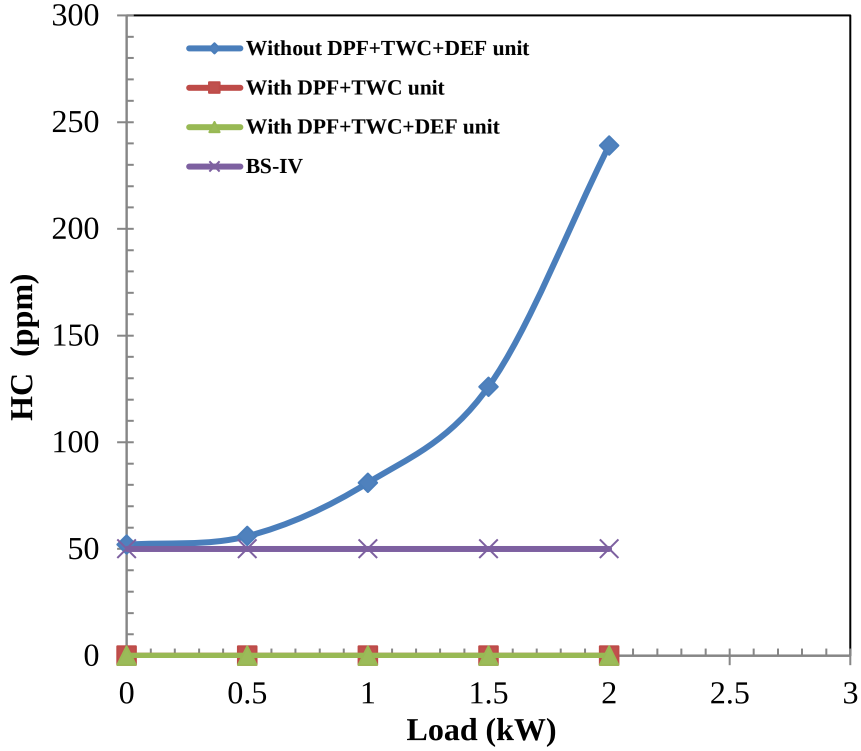

Fig. 4.3Variations in the unburnt hydrocarbon (HC)

The result for the variations in the unburnt hydrocarbon (HC) is presented in the Fig. 4.3, for all the three modes of operation. The HC is lesser when contrasted to the BS-IV standards for chosen engine at different loads. The HC increase proportionally with respect to load up to 2kW. This shows the presence of minimal value of HC at 0kW. From Fig. 4.3 it is noticeably observed that HC is high for 2kW without linking any unit. After connecting DPF+TWC and DPF+TWC +DEF units the HC variation is constant with 0.000 (%) values.

4.4. Nitrogen Oxides (NOx)

The result for the variations in the nitrogen oxides (NOx) is presented in the Fig. 4.4 for all the three modes of operation. The NOx increase proportionally with respect to load up to 2kW.This results the presence of an minimal value of NOx at 0kW. From Fig. 4.4 it is evidently observed that NOx is high for 2kW without linking any unit. After connecting DPF+TWC unit, the NOx increase proportionally with respect to load up to 1.5kW beyond this decreases. But the values of NOx were less when compared to above mode of operation. When DPF+TWC+DEF unit is connected, the NOx increase proportionally with respect to load up to 1kW beyond this decreases but the values were less compared to second mode of operation.

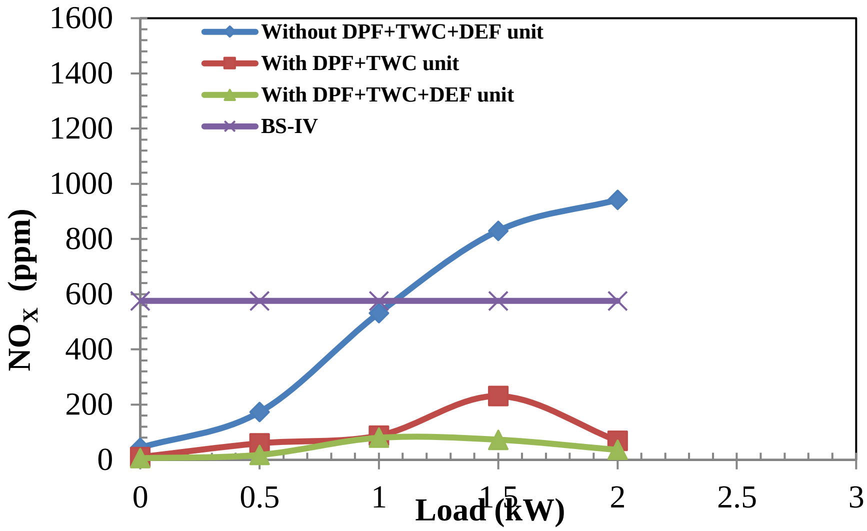

Fig. 4.4Variations in the nitrogen oxides (NOx)

4.5. Carbon Dioxide (CO_2):

The result for the variations in the carbon dioxide (CO_2) is presented in the Fig. 4.5, for all the three modes of operation. The CO_2 increase proportionally with respect to load up to 2kW.This shows the presence of minimal value of CO_2 at 0kW. From Fig. 4.5 it is obviously observed that CO_2 is highest for 2kW without linking any unit. After connecting DPF+TWC, the CO_2 increase proportionally with respect to load up to 2kW. But the values of CO_2 were less when compared to above mode of operation. When DPF+TWC +DEF unit is connected, the CO_2 increase proportionally with respect to load up to 2kW but the values are more compared to second mode of operation. As a universal law, more the CO_2 amount, higher capable the engine is working.

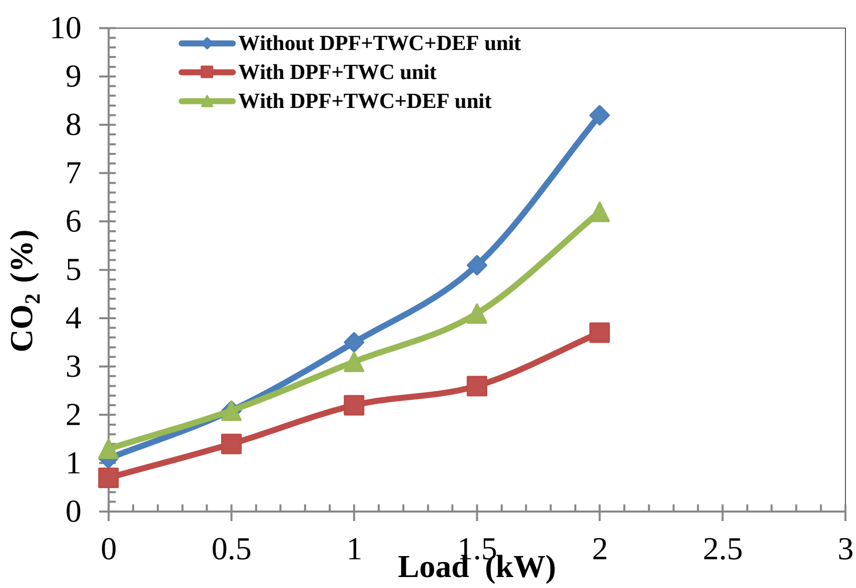

Fig. 4.5Variations in the carbon dioxide (CO_2)

5. Conclusions

Depending on the values got from the trials conducted, subsequent judgments are drafted.

* CO amount is zero for DPF+TWC and DPF+TWC+DEF unit linked, when contrasted without connecting any unit to exhaust pipe. 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 with retrofit arranged.

* Amount of HC is zero for DPF+TWC and DPF+TWC+DEF unit linked, when contrasted without connecting any unit at the tail pipe. 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.

* CO_2 is low for DPF+TWC and DPF+TWC+DEF unit linked, when contrasted without connecting any unit at the exhaust pipe. This is due to reactions taking place inside of catalytic converter.

* O_2 portion is higher for DPF+TWC unit, when contrasted to DPF+TWC+DEF unit is linked. However it is low in proportion for without any catalytic unit, when differentiated to DPF+TWC+DEF unit. This is because of participation of O_2 in oxidation reactions.

* 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.

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
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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