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Study on NO_x reduction capacity of catalytic coated cordierite monolith

Rekha Durairaj[a,]*, Neelakrishnan Subramanyan[a] and Divakar Duraiswamy[b]
[a]*Department of Automobile Engineering, PSG College of Technology, Coimbatore, TN 641004, India*
[b]*Department of Chemistry, PSG College of Technology, Coimbatore, TN 641004, India*

Legislation world-wide imposes stringent emission norms, particularly EURO V and beyond. In this regard, extensive research is being conducted for improving the existing filter design, material properties and developing alternative design, materials, testing procedures for more sensitive to reduce NO_X values. Cordierite ceramics are having good chemical and electrical properties like high thermal resistance, low dielectric constant, low thermal expansion coefficient, and high chemical and mechanical stability, which makes it for many industrial applications like manufacturing of the thermal insulation materials, optoelectronic devices, plasma display panels, solar panels, catalytic convertors etc. In this work, a pair of cordierite monolith with catalyst coating to NO_x storage and reduction was developed. The effectiveness of the catalysis was verified with engine exhaust gas analyser. The testing was carried out with diesel as fuel in a Kirloskar engine with Non-filter, NSR, and combined NSR-SCR system. The investigation was done for five trials with different emission parameters and analysed.

Keywords: Catalytic Converter, NO_X Storage and Reduction, Compression ratio.

Introduction

Vehicle outflow causes prompt and long haul impacts on nature. Vehicle depletes produce a wide scope of gases and strong issue, causing an unnatural weather change, corrosive downpour, and hurting the earth and human wellbeing. NO_x is the term used to indicate the vaporous blend of nitrogen oxide and nitrogen dioxide in different structures. NO_x is for the most part shaped at high temperature and weight when nitrogen and oxygen are joined because of the ignition of fuel. Among the six significant air contaminations (carbon monoxide, lead, NO_x, sulfur dioxide, PM and VOC's) NO_x is viewed as the most dangerous. NO_x is a fundamental element for the arrangement of surface ozone, a contamination that isn't promptly evaluated close to the surface with information from current space-based instruments [1]. Nitrogen oxides (NO_x) outflows from stationary and portable sources are not kidding dangers to nature since they can cause corrosive downpour, photochemical exhaust cloud, a dangerous atmospheric devotion and organic transformation [2]. The NO_x stockpiling and decrease (NSR) methodology is one of the choices for NO_x expulsion from diesel depletes, which works under cyclic oxidizing and diminishing conditions. More often than not, NSR impetuses for the most part contain respectable metals (for example Pd, Pt, and Rh) [3]. Commonplace NSR impetuses comprise of a high surface zone support (for example c-Al_2O_3, TiO_2, ZrO_2, or TiO_2-ZrO_2) [4]. A NSR impetus incorporates an essential oxide that chemisorbs NO_x under typical running conditions, and intermittently, a reductant is sustained to the fumes that desorbs and decreases the put away NO_x [5]. NSR is done in the lean NO_x trap (LNT), which is worked by cycling between fuel-lean and fuel-rich conditions. NO_x is put away under lean conditions as nitrates and nitrites on salt metal or antacid earth metal parts [6]. During the lean time frame (term of ~minutes), NO_x is caught on the Ba stage as $Ba(NO_3)_2$ and $Ba(NO_2)_2$, predominantly through oxidation of NO to NO_2, and on CeO_2 at low temperature (<250 °C). During the rich time frame (span of ~seconds) reductants from fragmented fuel burning items (H_2, CO, HC) are brought into the fumes stream [7].

Specific impetus decreases selective catalytic reduction (SCR) framework is at present the best decision to dispense with NO_x discharges from diesel engines. The SCR of NO_x has been in wide use for decades particularly in stationary applications like gas turbines, Boilers, power plants etc.The SCR consist of monolith similar to that of NSR but the catalyst used over monolith is a zeolite powder which may be naturally occurring or synthesized. The reducing agent used is urea/ammonia to convert NOX into nitrogen (N_2) and water vapour (H_2O). NO_x emanations in the fumes gas can be wiped out with reductants in the SCR framework. Smelling salts (NH_3) is the most usually utilized reductants and has high transformation productivity in SCR of NO_x [8]. Particular synergist decrease of NO_x by (urea/SCR) is the most proficient innovation for the

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*Corresponding author:
Tel : +919994367552
Fax: +04222573833
E-mail: reksun02@gmail.com

after treatment of NO_x from diesel engine fumes to meet stringent emanation guidelines, including EURO VI and SULEV. For this, the SCR impetus is required to be dynamic, especially in the low temperature systems, since the typical fumes gas temperature from a diesel engine going from 100 - 250 °C for light obligation to 200 - 350 °C for hard core diesel engines is fundamentally lower than that from a gas engine, and the fumes temperature from a propelled diesel engine for high eco-friendliness is predictable to turn out to be even lower [9]. Iron oxide is a commonplace dynamic fixing or advertiser in NH_3-SCR impetuses, which shows great NH_3-SCR movement and N_2 selectivity, on account of its inalienably naturally neighbourly character, its unmistakable warm strength and its remarkable H_2O/ SO_2 obstruction [10]. LNT and SCR zoning in double layer impetus improved NO_X decrease productivity and introduced the possibility to diminish the costly platinum gathering metals (PGM) stacking by up to 40% from that of LNT impetus without debasing its de-NO_x execution under mimicked diesel fumes conditions [11]. Temperature based model methodology was performed by [12] to advance SCR adjustment for BSIV standards utilizing the alignment procedure. The structure of the SCR framework included impetus choice, complex controller advancement like urea dosing procedure and the communication between engine arrangement and after treatment framework. A few looks into were done in the past on NO_x stockpiling and decrease (NSR) [13] and specific impetus decrease (SCR) exclusively to diminish NO_x discharge in car diesel engines. The examination includes the advancement and testing of an exhaust system with a joined NSR-SCR impetus for diesel engine fumes frameworks, for improving the viability of NO_x outflow decrease in diesel engine debilitates with consolidated NSR-SCR impetus. The exploration proposes an AI calculation to enhance test information dependent on demonstrating. The presentation of the created catalyser is contrasted and recreation model and test outcomes. It is watched the proposed advancement methodology can improve the NO_x decrease and the effectiveness of the diesel engine fumes frameworks.

Literature Review

Vehicular engines working under lean consume conditions are ending up progressively prevalent because of their better efficiency as looked at than regular Otto gas engines. Be that as it may, the lethal NO_x fumes gas parts of lean-consume engines can't be productively evacuated with three-way impetuses, which are compelling just under stoichiometric conditions. Therefore, particular reactant decrease (SCR) of NO_x utilizing urea as a reductant has been produced for versatile lean NO_x evacuation Zhang et al. [14], Alcalde-Santiago et al. [15] portrayed an idea comprising of a macroporous bearer free impetus. An alternate Cu-containing Sr-Ti NSR impetus with a macroporous system was integrated, and its greatest NO_x stockpiling limit (1,500 μmol NO_x/g catalyst) essentially outperformed that of traditional $Pt/Ba/Al_2O_3$ details (~600 - 800 μmol NO_x/g catalyst). Diesel engines can possibly agree to the much progressively stringent CO_2 emanations enactment, which will be applied in the main vehicle markets worldwide in the coming years. E. Srinivasa Rao et al. [16] discussed about the solid state method which was adopted to prepare Cordierite ceramics of different particle sizes. Cordierite ceramic's particle size during the sintering process influence whether that material is suitable for kiln-furniture application. Lafossas et al. [17] displayed a response model for oxygen stockpiling which impacts the accessibility of diminishing specialists' for desulfation. Krishnan et al. [18] displayed a technique to build the engine torque by expanding the comparability proportion and at the same time controlling the NO_x discharges by embracing a mix of EGR and H_2-SCR. The cold EGR methodology was received, where the re-coursed fumes gas was cooled to a specific temperature. Kwang-Ho Lee [19] was discussed mechanical properties and wear characteristics of yttria-stabilized ZrO_2 monoliths ceramic. Yuan et al. [20] clarified a NH_3 slip control for diesel engine specific synergist decrease after-treatment framework. The NH3 slip control execution of the proposed technique was tentatively approved in the European transient cycle. Han et al. [21] built up a control situated lean NO_x trap (LNT) model for the LNT recovery reason to gauge the NO_x stockpiling portion, NO_x focus out of a LNT impetus and a LNT impetus bed temperature.

Park et al. [22] displayed the mechanical properties and crystallization of ceramic cores depends on the silica particle morphology, it also influences the mixing, flow, and sintering behaviour of feedstock. (Hydrocarbon-specific reactant decrease (HC-SCR) is a de-NO_x framework for diesel engines, which uses locally available fuel as the reductants to improve the framework. Gu et al. [23] examined the impacts of including hydrogen the proficiency of NO_x decrease by means of HC-SCR utilizing different reductants. Cheng et al. [24] introduced another impetus for NO decrease from BEA zeolites saturated with various metals bolstered by the particle trading technique. Cu-BEA indicated high synergist movement for NO decrease by CO and H_2 at 300 - 500 °C, while Co-BEA demonstrated the high reactant action of NO decrease by CH4 at 400 - 500 °C. Resitoglu et al. [25] decided the NO_x transformation effectiveness of ethanol-biodiesel blends in the particular reactant decrease framework at various engine burdens and distinctive fumes gas temperatures under genuine working conditions. It was discovered that the reductants with 15% biodiesel and 85% ethanol, had the most elevated transformation execution. De-La-Torre et al. [26] arranged and tried for NO_x expulsion from diesel and lean consume engines fumes gases by coupling NSR-SCR frameworks containing a Pt-BaO/Al_2O_3 NSR stone monument and Cu/CHA, Cu/ZSM-5 (or) Cu/BETA SCR impetuses. In past investigations, different enhancements were performed independently on both NSR and SCR in diesel engine fumes frameworks. Enrique Rocha-Rangel [27] discussed about the preliminary characterization of the microstructure and its composition features subsequent to the cycle of in-situ process. The dense, fine and homogeneous microstructure of Al_2O_3 based composite materials with reinforcement particles of Ti_xAl_y was discussed. Enhancement of joined NSR-SCR impetus is a novel idea proposed in this exploration to improve the NO_x decrease and to create powerful exhaust systems the diesel engine fumes frameworks. In this way, the proposed methodology lessens NO_x emanation with ease and takes out the smelling salts slip and spares space required for dynamic measurement control in diesel engines of autos separately.

Proposed Research Work

An extended diesel engine populace has weight on controlling diesel usage and NO_x discharges. The fundamental headway in diesel outflow control was cultivated through engine developments, fusing changes in the start chamber arrangement, improved fuel structures, charge air cooling, and uncommon thought with respect to lube oil usage. With the growing enthusiasm for a cleaner circumstance and better air quality, a diesel engine creator is constrained to satisfy stricter guidelines for gases release of an engine. Improved data of the likelihood to diminish these sorts of releases could help engine fashioners to modify their engines with successful outpouring control frameworks. Despite the fact that, by far most of the writing required exhibits a slight augmentation in NO_x outpourings when using a differing synergist channel. The fundamental objective of this work is to furnish a capable fumes framework with a mix of NSR and SCR technique. The process flow chart of this work shown in Fig. 1. The diesel engine exhaust emission has been tested without any filtration aids, with NSR filter and with NSR and SCR filter along with the preparation of NSR and SCR catalysts. Finally, the filter capability towards NO_x decline is assessed with different compression ratios and loading conditions.

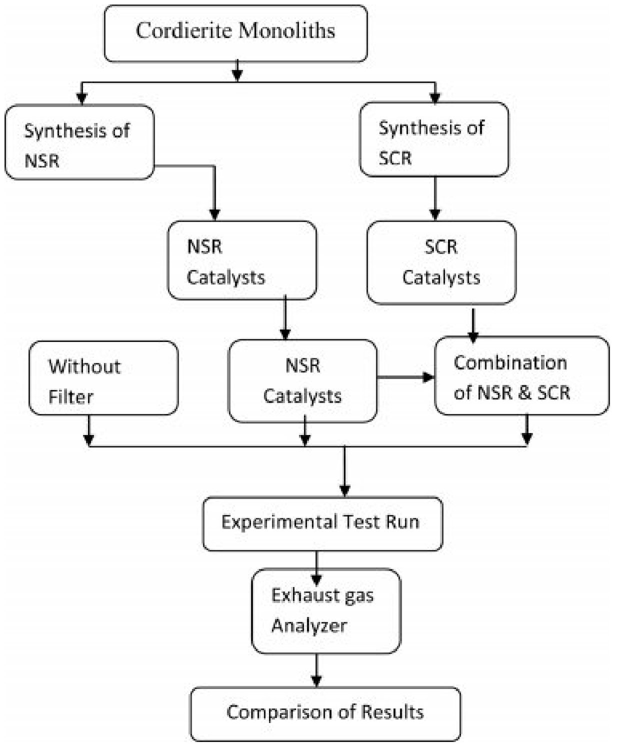

Fig. 1. Process flow chart.

Experimental Setup and Design

More toxic substances are there in diesel engine exhaust emission. Catalytic converters play an important role to minimize such harmful gases into harmless gases. In this research paper, the synthesis of NSR and SCR catalysts are explained along with experimental test results.

Materials and methods used for experimentation

In this experimental research, the cordierite monolith has been synthesized with suitable catalyst to obtain required NSR and SCR catalytic converter. A single cylinder diesel engine has been tested without filter, along with NSR converter, Combination of NSR and SCR converters. Figure 2 shows the schematic representation of experimental setup.

Catalytic converter

In the diesel engine exhaust gas, the harmful gases like carbon monoxide and unburned hydrocarbon concentrations are more, the catalytic converters present in the exhaust pipe has oxidized the carbon monoxide, hydrocarbon emissions into harmless carbon dioxide and water vapour. This was because of the chemical response of the catalytic converter [28].

Diesel engine

In this experimentation, single cylinder variable compression ratio diesel engine was utilized for the testing of catalytic converters. Diesel is more and more efficient, they should utilize less fuel, produce less carbon dioxide (CO_2) emissions, and contribute less to global warming [29].

Engine Specification

Engine - Single Cylinder Four stroke variable compression ratio, water cooled Diesel engine

HP/kW : 5/3.7

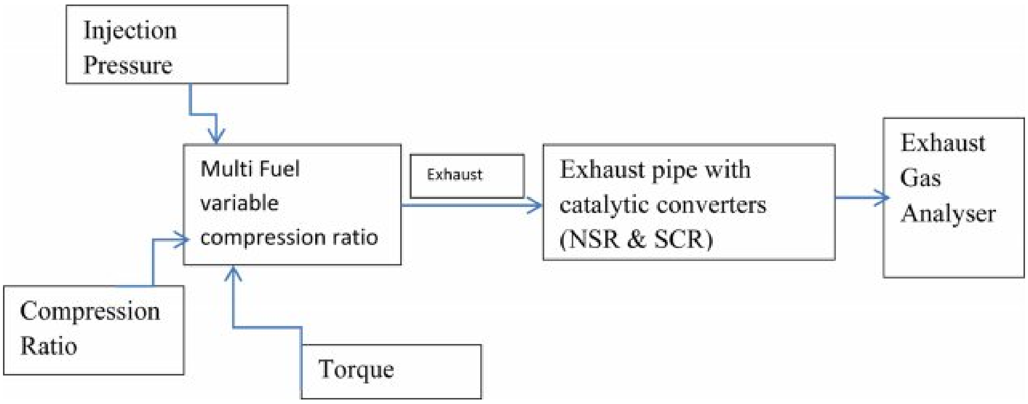

Fig. 2. Schematic setup of experimental setup.

RPM : 1500
Bore Diameter : 87.5 mm
Stroke : 110 mm
Compression Ratio : 17.5 to 20
Injection pressure : 80-230 bar
Torque : 0-20 Nm

The engine specifications of the Kirloskar engine utilized in this experimentation are as given above. The four-stroke diesel engine coupled with eddy current dynamometer for varying load conditions along with compression proportion of 17.5:1 to 20:1 is taken for testing purposes [30].

Figure 3, shows the Kirloskar diesel engine along with loading device of eddy current dynamometer which is used for experimentation. A piezoelectric transducer part, sensors are associated with the engine cylinder and crank angle sensor and charge amplifier for obtaining resolution 1 degree and 5,000 rpm with TDC marker pulse is mounted to the flywheel and for gaining signals for engine indication. To measure the percentage of CO, HC, CO_2, O_2, and NO_x (ppm) emissions the AVL gas analyser has been utilized.

Fig. 3. Kirloskar Diesel Engine.

NO_x Storage and Reduction & s Elective Catalytic Converter

General aspects of the NSR (NO_x Storage and Reduction) catalysis

NO_x storage and reduction is considered as one of the most promising technology for NO_x removal from diesel engine exhausts gases. It can also be mentioned as Lean NO_x Traps (LNT). Recent excellent reviews can be found in the literature on this technology.

Working:

The NSR catalysts run cyclically under lean environment (oxidizing) and rich environment (reducing), being defined by the corresponding Air/Fuel ratios. While running on the road, lean and rich conditions have to be used in an alternative way. Under lean conditions, with excess of oxygen i.e.; high (Air/Fuel), NO_x are adsorbed (alkaline or earth-alkaline compounds) by the catalyst, and later under rich conditions (Air/Fuel < 14.63) the stored NO_x are released and reduced. Most studies in the literature have used storage material as Barium, reduction material as H-Zeolite.

NSR Mechanism

NSR mechanism can be explained by the five following steps:

(a) Oxidation of NO to NO_2 (lean conditions, oxidizing environment).
(b) Adsorption of NO_x as nitrites/nitrates on the storage sites (lean period, oxidizing environment).
(c) Injection and evolution of the used reducing agent (H_2, CO or HC).

(d) Release of the stored NO_x from the catalyst surface to the gas stream (rich period, reducing environment).
(e) Reduction of NO_x to N_2 (rich period, reducing environment).

Procedure for the preparation of catalyst

The procedure for the preparation of NSR catalyst was detailed below

Wash coat preparation:

This section focused on the preparation procedure of monolithic NSR catalyst. In real application, the mechanical properties of the catalyst temperature and vibrational strengths may vary due to exhaust gases. Due to high thermal stability and low expansion coefficient, the Cordierite ($2MgO.2Al_2O_3.5SiO_2$), has been chosen as the base material in automotive application. However, this material exhibits a low surface area which is not suitable for the subsequent incorporation of the active phases.

Consequently, the first step of the catalyst preparation consists of the monolithic substrate wash coating with a high surface area oxide, usually alumina. The most common wash coating procedure is carried out by dipping the monolith into slurry, which is usually of alumina. The procedures are stated below

Step 1: Calculate the weight of the monolith.

Step 2: Take 100 mL of distilled water and stir using magnetic stirrer.

Step 3: Add 10 g wt.% of γ-Al_2O_3 and allow it to stir well for 5 min at 450-500 rpm.

Step 4: Add glacial acetic acid (CH_3COOH) gradually and stir well.

Step 5: Check the pH level using pH meter. Step 6: Repeat the above step until pH of 2-3 is obtained.

Step 7: Allow the solution to stir well for 30 minutes.

Step 8: Dip the cordierite monolith substrate in the slurry using tongs for 10 seconds.

Step 9: Clear the pores of the monolith using blower.

Step 10: Dry it in oven for 20 minutes and allow it to attain room temperature.

Step 11: Again calculate the weight gained over monolith.

Step 12: Repeat the steps until required amount of γ-Al_2O_3 gets coated over the substrate [31]. It is studied that the threshold value of particle size around 5 µm which is coincident with the size of the cordierite macropores; larger alumina particles do not penetrate into the macropores of the substrate resulting in a poor anchoring of the alumina layer. Therefore, the smaller the particle size in the slurry, the higher the alumina layer anchoring [32]. Another characteristic to be controlled is the stabilization of the alumina slurry so as to avoid the particles from settling down. It is studied that addition of some acetic acid to shift pH between 3 and 4 improved the slurry stabilization. Furthermore, the addition of acetic acid up to 2.5 mol L^{-1} (pH = 2.6) decreased considerably the viscosity of the slurry, permitting the use of concentrated Al_2O_3 slurries without penalization in the layer homogeneity [31]. Initial weight of the monolith was 16.9538 g. The weight gained by the monolith after tenth immersion was 3.9360 g. The amount of γ-alumina loaded to the monolith depends on the volume of the monolith [31].

Platinum incorporation

The next step in the catalyst preparation is the incorporation of the active phases. As already mentioned, NSR catalysts are usually composed of an alkali or alkali-earth oxide and a noble metal deposited onto the alumina. The most common metal used for NSR catalyst formulation is Pt, whereas BaO is normally used as the storage component. The order of the incorporation steps of the active phases Pt and Ba is important, especially when operating at higher temperatures; a higher storage capacity is obtained when impregnating Pt/Al_2O_3 with Ba than when impregnating Ba/Al_2O_3 with Pt, increasing the storage value as much as 54% when adding Ba in the last step. Platinum can be incorporated following two different procedures, conventional wetness impregnation and adsorption from solution. In this work adsorption method was followed due good compromise between platinum dispersion and thermal stabilization of the catalyst [31]. In the adsorption procedure, the monoliths were immersed in an aqueous solution with the adequate concentration of Pt. The monoliths were maintained immersed in the solution for 24 h so as to reach the adsorption equilibrium. Then, the monoliths were removed from the solution, the excess of liquid blown out and finally the monoliths were calcined at 500 °C, respectively.

Barium incorporation:

The last step in the NSR catalyst preparation is the incorporation of the NO_x storage component, i.e. barium. The precursor used was barium nitrate and two different procedures were followed: wetness impregnation and incipient wetness impregnation (also known as dry impregnation).

In this work wetness impregnation method was adapted; the monolith channels were filled with an aqueous solution containing the desired amount of barium. Later the monolith was dried and calcined.

The weight gained by the γ-alumina coated monolith after ninth immersion was 1.742 g as per requirements [31].

General aspects of the SCR (Selective Catalytic Reduction) catalysis

The selective catalytic reduction of NO_x is widely used decades before, particularly in stationary applications like gas turbines, Boilers, power plants etc. Now, SCR is being used in heavy duty diesel vehicles widely in Europe to meet Euro-4 and later emission standards.

The SCR consist of monolith similar to that of NSR but the catalyst used over monolith is a zeolite powder which may be naturally occurring or synthesized. The reducing agent used is urea/ammonia to convert NO_x into nitrogen (N_2) and water vapour (H_2O).

Working

The selective catalytic reduction system reduces the NO_x with the help of Metal supported catalyst coated over wash-coated ceramic monolith. In SCR the catalytic action is based on the amount of NO_x coming from the exhaust of the engine. It is not working in lean and rich condition as like in NSR. The SCR consists of monolith coated with metal supported zeolite catalyst and ammonia tank in which the urea contains 32.5% of ammonia with de-ionized water.

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

SCR Mechanism

a. Dynamic dosage injection of urea based on the NO_x ppm value from the exhaust gas.

b. Reducing the NO_x with the help of NH_3 stored inside the zeolite and converts it into nitrogen and water.

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$$

$$4NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6H_2O$$

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2$$

Catalyst preparation

The catalyst preparation method for ZSM5 & H-Beta SCR catalyst is same. The H-Beta zeolite is mixed with the copper nitrate with de-ionized air at 60 °C, for 24 hours for ion exchange. If the Zeolite is in its NH_4^- zeolite form then it is to be calcined at 500 °C, for 4 h [31]. For uniform dispersion of catalyst over the monolith and for better catalytic action the monolith powder has to be in nano size. For reducing the size of metal powders the method used is ball milling. The calcined Cu-Zeolite is mixed with 20% colloidal silica and coated over the monolith by dip coating. The process is continued until the monolith had been coated with the required amount of weight percentage of the Cu-Zeolite catalyst. The following steps were to be carried out during dip coating for uniform coating of catalyst.

Step 1: The monolith is dipped inside the solution which was stirred by ultrasonic bath for better particle dispersion.

Step 2: Later water is removed by blowing air using an air blower inside the monolith.

Step 3: The monolith is now heated inside a furnace at 100 °C for about 15 min to remove the water and make it dry.

Step 4: Once the monolith was dried, it is cooled to room temperature through natural cooling and weighed to determine the weight gained for individual iteration.

In this work after fifteenth immersion the weight gained by the monolith was 1.24 g as the requirement [31].

When the required weight percentage of catalyst has been loaded over the monolith it is calcined for about 4 hours at 550 °C, for catalyst stabilization on the monolith and to remove the volatile fractions.

Design and Fabrication of Reactor Prototype

In this research, the proposed design of catalytic convertor to accommodate both NSR and SCR catalyst has been developed based on the size of prototype monolith.

Design Constraints:

- Monolith size.
- Exhaust outlet diameter
- Flow rate of gas for the prototype.
- Temperature of exhaust gas.
- Flow distribution.
- Catalyst coating (Wt. %).

The two catalytic converters NSR and SCR are utilized for converting dangerous exhaust gases into harmless gases. In order to measure the required parameters like emission levels and temperatures vent out lets and thermocouples has provided at the start, in between NSR and SCR catalysts and at the end. This output taken to the analyser for measurement.

Exhaust outlet diameter

The exhaust outlet diameter decides the velocity of the exhaust gas from the engine and it is measured as 1″ using Vernier calliper.

Flow rate of gas

The flow rate decides the monolith size to be incorporated. Monolith is used for the complete conversion of the exhaust emission. But here, as the monolith size is constant, the flow rate has been adjusted with respect to the monolith size. The flow rate of exhaust gas can be calculated theoretically as well as practically. The practical flow rate can be calculated using an anemometer which measures the velocity of the exhaust gas. Flow rate is the product of exhaust gas velocity and cross sectional area.

Temperature of exhaust gas and catalytic converter

The temperature of the exhaust gas decides the conversion rate of the catalytic converter and the conversion efficiency. Since the catalytic action is more at elevated temperatures [33], the temperature of the catalytic converter should be maintained 250 °C from the beginning in order to achieve catalytic action at all conditions.

Flow distribution

Flow distribution refers to the distribution of exhaust gas throughout the monolith coated with the catalyst for maximum contact of the exhaust gas with the catalyst. This flow distribution is based on the inlet and outlet cone angle and at the same time larger cone angles results in vortex inside the monolith which create backpressure. So cone angle 45° has been selected.

Thickness of catalyst

Coating of catalyst over the monolith is based on weight percentage of monolith's total weight [31]. If the coating percentage is higher than the standard value, then the catalyst will block the pores of the monolith, which will result in high back pressure as well as reduced catalytic action.

Fabricated prototype

Figure 4 shows the fabricated proto type exhaust pipe to accommodate the NSR and SCR catalysts. Baffle is located before the location of the catalysts to direct the flow of exhaust gases. Flow regulating valve also provided to regulate the quantum of exhaust gas to be entered into the catalysts section.

Experimental Procedure

The testing was done by using diesel as fuel on a Kirloskar engine that was at 1,500 rpm constant speed engine. The fabricated proto type exhaust pipe was fitted to the diesel engine fumes with a T-joint. The testing was completed by applying different load and compression ratio to find the efficiency of catalytic converters. An eddy current dynamometer [34] was utilized to load the engine at 0, 50% N-m, and 100% N-m loading conditions. The testing was done under different laboratory conditions, for example, shifting temperature and stream rate of exhaust gases. In the running conditions, diverse info parameters like fuel consumption, indicated power thermal efficiency etc. also noted at different conditions. The experiment was conducted at different torques in N-m like 0, 10, 20, and compression ratios like 17.5, 18.75 and 20. The testing was completed without filter, with NSR converter, and with NSR-SCR converters. The exhaust emission gases coming out of the exhaust pipe after catalytic reaction were associated with the gas analyser and sensors to recognize the percentage of each gas emitted. The emission performance also tested with the engine in real-time conditions with the assistance of expert combustion monitoring systems [35].

Results and Discussion

In this experimentation, the exhaust gases from a diesel engine are examined and are classified. For varies compression ratio (CR), and Torque (L) of the diesel engine, the experimentations are done without the utilization of filter, with NSR converter, and with NSR and SCR converters. Figure 5, shows the CO, CO_2, NO_X, O_2 and HC emission values at different output conditions like without filter, with NSR and with NSR and SCR filters at compression ratios of 17.5, 18.75 and 20 respectively. When the compression ratio increases from 17.5 to 20, then the inside pressure of the cylinder increases, thereby increasing the level of combustion process. This results in increased CO_2 emission and lower CO emission. The NSR and SCR filters also help to reduce the CO emission up to 200% at higher compression ratios. It is also observed that the NO_x emission increased owing to the higher pressure inside the cylinder due to high compression ratio. This leads to increase of heat release rate. The high temperature and pressure inside the cylinder agitates NO_x emissions. Even though NO_x emission was high at high compression ratio, the percentage of increase of NO_x without filter was 132% but after NSR and SCR reaction the percentage of increase of NO_x at high compression ratio was only 20%. This shows the efficiency of the filters. It is observed that if the NO_x value decreased in the exhaust, it is due to increased O_2 emission to the atmosphere. When the compression ratio increases, the flame propagation is much faster, there by shortening the combustion process. This increases the charge temperature and reduce the

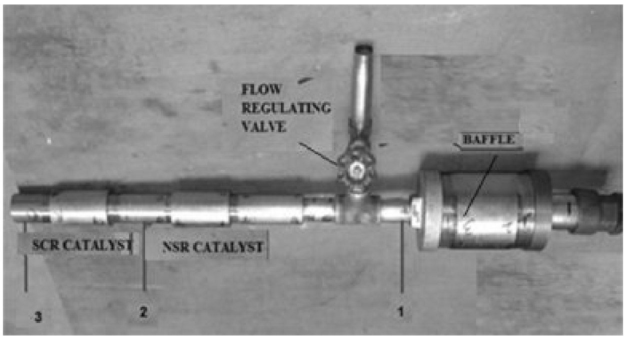

Fig. 4. Fabricated Exhaust pipe for the placement of NSR and SCR catalysts.

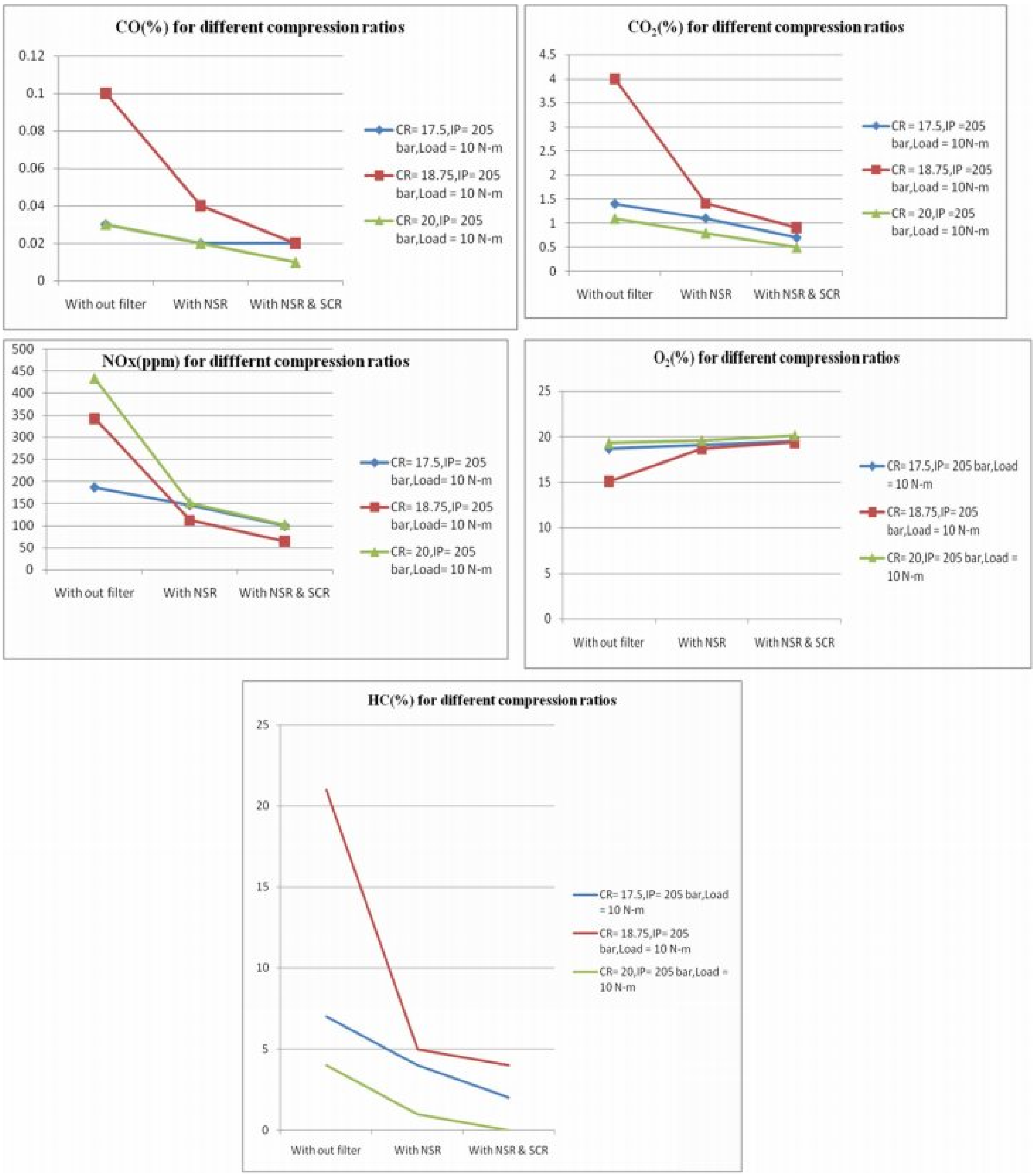

Fig. 5. Emission Readings at different compression ratios.

HC emission to a certain extent. In this work the HC emission is found to be almost zero at high compression ratios after NSR and SCR filter reaction process as shown in Fig. 5. However, the CO,CO_2 and HC emissions were higher at compression ratio of 18.75 when compared to compression ratio of 20. Significantly lower O_2 emission at this compression ratio indicates that there may be a chance of incomplete combustion process due to low cylinder wall temperature, too slow flame speed and in sufficient oxygen content.

The test was also conducted at different injection pressures while keeping the compression ratio and load constant. Spray formation and air-fuel mixing are found to be influenced by injection pressure. The velocity and momentum of fuel droplets coming out of the nozzle depends upon the injection pressure.

When the injection pressure is high finer atomization and better air fuel mixing has been occurring, resulting in high temperature inside the cylinder. Hence NO_x emission increases at high injection pressure. Figure 6 show the emissions readings at different injection pressures. It is seen that at 230 bar injection pressure, the NO_x emission reduction is achieved with NSR and SCR filter as 619% compared with no filter condition. The corresponding CO, CO_2 and HC emissions at various injection pressure are as shown in Fig. 6.

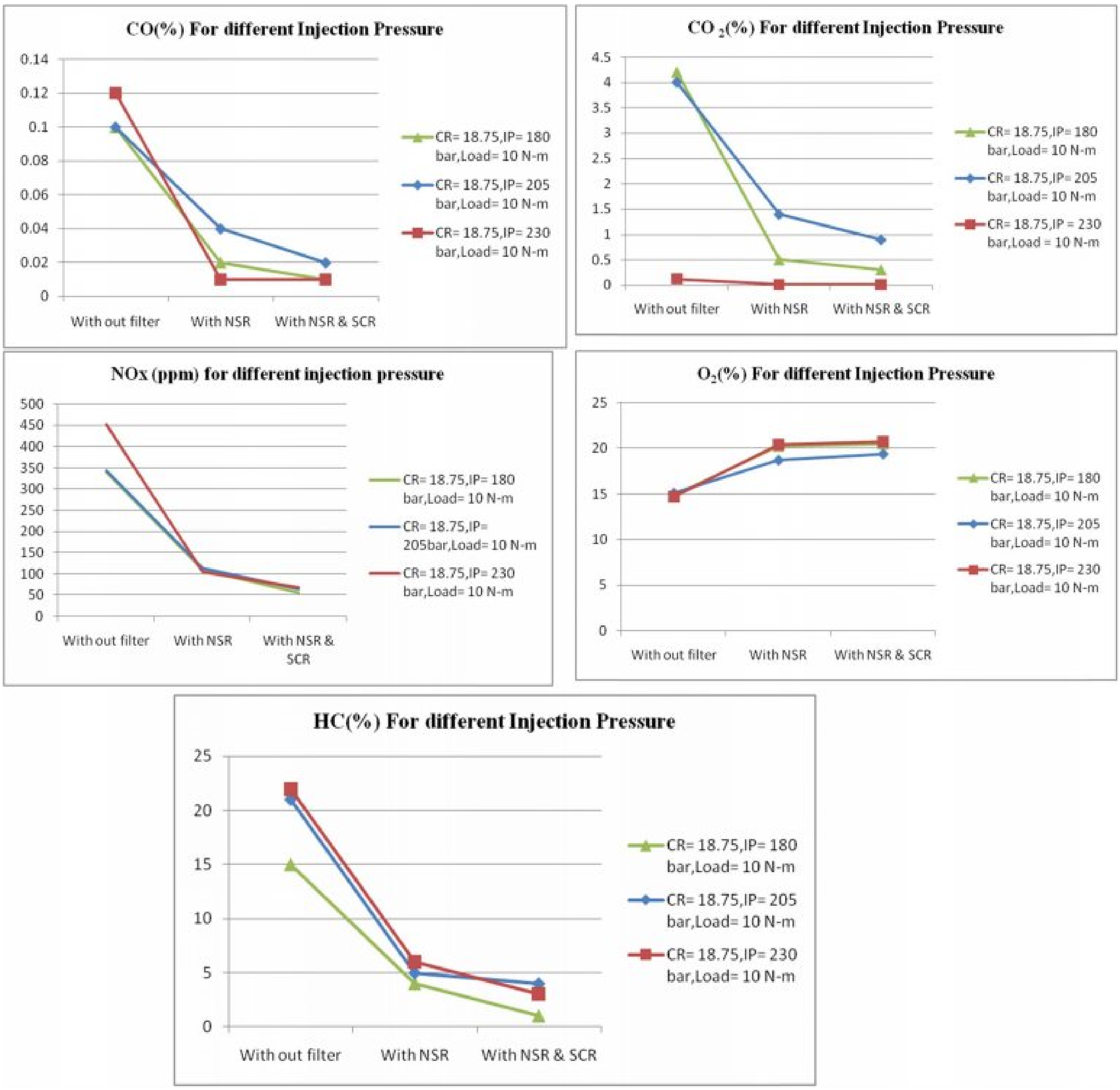

Fig. 6. Emission readings at different injection pressures.

The test was also conducted at different loading conditions keeping the compression ratio and injection pressure as constant. It is observed when the load increases the NO_x emission also increases due to high pressure in the air fuel mixture inside the cylinder

Figure 7 show the emission readings at different loading conditions. At full load condition the NO_x emission has been reduced to 214% when compared with no filter and with NSR and SCR filter. Proportionately O_2 emission also increased noticeably. When the engine ran at full load condition, the amount of oxygen inside the cylinder was high but to maintain the constant speed of the engine more fuel is consumed when compared to no load condition. This may lead to too large diesel droplets or if insufficient turbulence or swirl is created inside the combustion chamber, this results in high CO emission at full load condition. But the percentage of CO emission is found to decreases to 110% while using NSR and SCR filters compare with no filter at full load conditions. The % HC emission is compared and shown in Fig. 7.

Comparison of performance between actual and lab experiments (Table 1).

Conclusion

This examination can be extended in the future by changing the selective catalytic reduction system to non-selective catalytic reduction system, which utilized a precious metal-based catalytic converter. These will help to reduce the NO_x, unburned HC, and CO and these can directly be connected to IC engines with fuel-

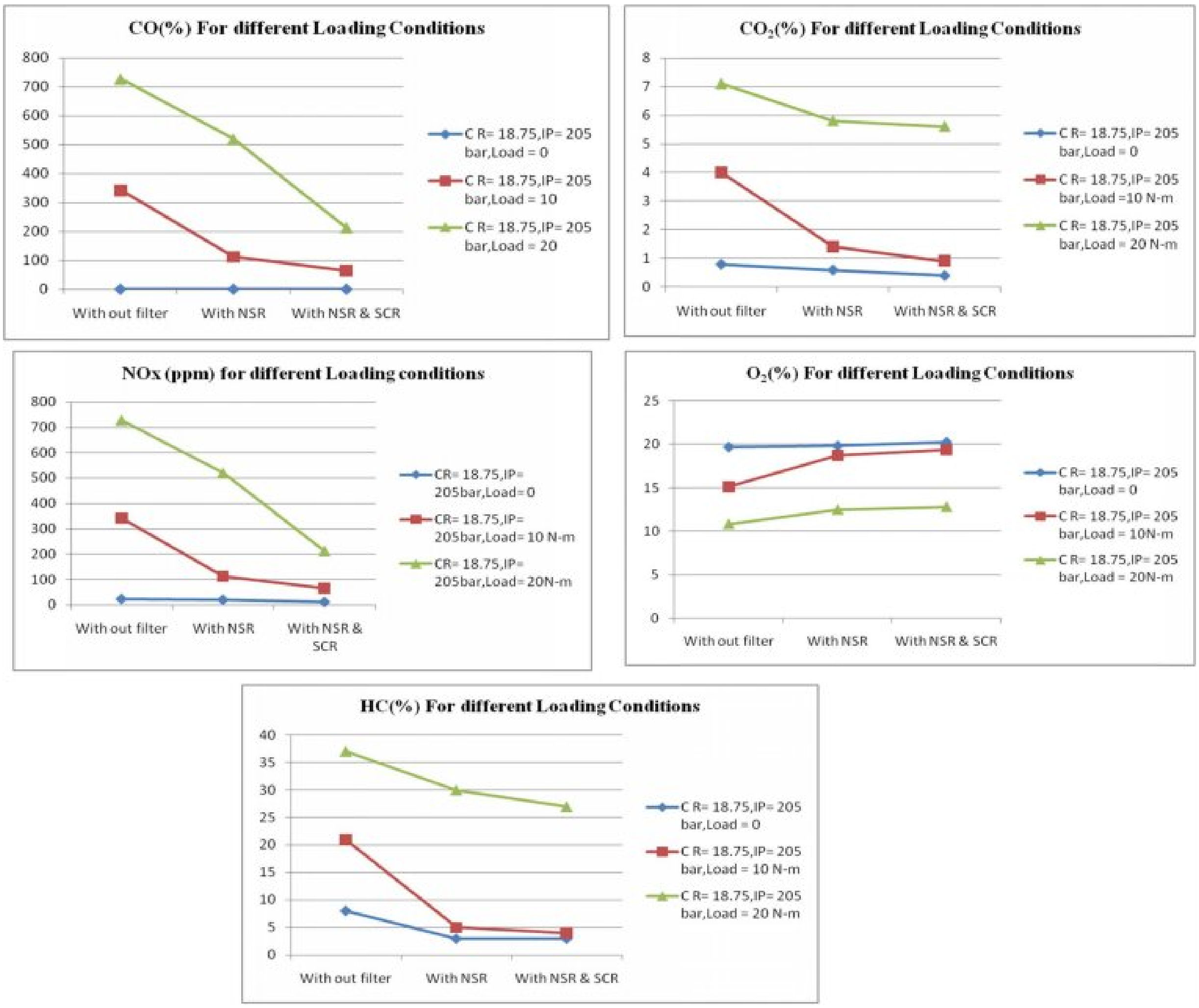

Fig. 7. Emission Readings at different Loading conditions.

Table 1. Percentage difference of performance between actual and lab experiments.

CR	IP (bar)	Load (Nm)	Conditions	Laboratory results	Real-time results	Percentage difference in NO_x
				NO_x (ppm)		
18.75	205	0	Without filter	24	27	12.5
			With NSR	21	23	9.5
			With NSR & SCR	12	14	16.7

rich ignition systems respectively.

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