Reduction in Exhaust Emission Using Constantan Catalyst in the Diesel Engine

Vivek Kumar Banerjee, Tanmay Agrawal, Basant Singh Sikarwar and Mohit Bhandwal

Abstract Catalytic convertor plays an important role in reducing harmful emissions in the form of NO_x, HC, and CO. Various technologies have been developed to reduce vehicular emissions; however, it comes with the expense of engine performance and cost. In this research, harmful emissions from the exhaust gases of diesel engines are reduced without compromising the engine efficiency and cost-effectiveness. In this context, a new monolith is designed and fabricated with copper–nickel alloy (constantan wire) as catalyst enclosed by an aluminum casing. This device is tested on a single cylinder diesel engine at 1500 rpm and it shows 60% NO_x, 60% CO, and 35% HC conversion efficiency. This research is helpful for partial replacement of the platinum-grade material used in the present catalytic converter.

Keywords Catalytic converter · Constantan · Exhaust emissions · Diesel engine

1 Introduction

The biggest challenge of the twenty-first century is the increasing amount of pollution in the atmosphere. The major sources of air pollution from the combustion of fossil fuels are NO_x, CO, CO_2 [1, 2]. These harmful emissions are disrupting the complex, dynamic natural gaseous system of our atmosphere that supports life. Oxides of nitrogen and carbon cause severe environmental problems like acid rain, ozone layer depletion, global warming, etc. [3]. But, among all these oxides NO_x is the biggest concern. One study reported that the contribution of automobile in NO_x emission is 49% and from power plant is 46% [4]. Report also claims that as the NO_x level gets doubled into the atmosphere the ozone layer is depleted by 12% and atmospheric temperature rises by 0.3 [5, 6]. Government has imposed stringent norms on automobile industries to reduce the amount of exhaust emissions. In India, Bharat Stage 6 is on the verge of getting applied. So, several researches are going on for

V. K. Banerjee (✉) · T. Agrawal · B. S. Sikarwar · M. Bhandwal
Department of Mechanical Engineering, Amity University Uttar Pradesh, Noida, Uttar Pradesh, India
e-mail: vivekbanerjeee@gmail.com

M. Kumar et al. (eds.), *Advances in Interdisciplinary Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-13-6577-5_15

purification of auto exhaust by using catalytic devices. In NO_x catalyst research, two reaction procedures have been proposed; direct decomposition reaction and reduction [7–10]. The reaction rate of direct decomposition is very slow, so application of this scheme is hardly considered. Whereas reduction reaction is comparatively fast and it takes place in presence of CO, H_2, and hydrocarbons as reducing agent which are present in exhaust gases [11]. Many technologies have been developed to use these simple reaction schemes for auto exhaust reduction. Catalytic convertor is one of the technologies that are presently working in this context. It is a device used to reduce vehicular emissions by conducting two simple chemical reaction processes, i.e., reduction of NO_x and the oxidation of hydrocarbons and carbon monoxide, by using the catalyst platinum, palladium, and rhodium [12, 13]. The basic reactions that occur inside the catalytic converters are [14]

$$2CO + O_2 \rightarrow 2CO_2 \tag{1}$$

$$2NO \rightarrow O_2 + N_2 \tag{2}$$

$$2NO_2 \rightarrow N_2 + 2O_2 \tag{3}$$

$$HC + O_2 \rightarrow CO_2 + H_2O \tag{4}$$

The use of these platinum-grade material has dominated in reducing the vehicular pollution, but they all are very rare and therefore costly [15–17]. Thus, it leads to the development of technologies that can explore other cheap sources and methods to reduce the vehicular emission. Some of the promising researches have been observed in the development of the catalytic materials, which includes ammonia-based catalysts, carbon-supported catalysts, silica catalysts, zeolite-based catalysts like ruthenium zeolite catalyst [18–22]. Of late split injection strategy has drawn the attention of the researcher due to its effective NO_x reduction capacity along with reduction in soot formation and piston work trade-offs [23]. Studies show that oxides like cerium oxide (CeO_2) and titanium oxide (TiO_2) have good redox properties. M. S. Hedge in 2010 proposed preparative method to form catalysts of different combinations of CeO_2 and TiO_2 with the noble metals like platinum, palladium, and rhodium [24]. In 2006, Nitin Labhsetwar studied the application of perovskite-type catalysts with ABO_3-type structure which posses very good thermal stability characteristics [25]. Clearly, the efforts were made to reduce the cost of catalytic converter without compromising with the catalytic activity. However, in the year 2010, S. Chauhan expressed his views on the noble metals like platinum, palladium, and rhodium which are the best option available for reducing the exhaust emissions, although they are very expensive and in a limited supply [26]. He also studied the different catalysts like iridium, copper, ruthenium, zeolite, and nickel. N. Nedunchizehian in his paper shows the effects of nickel–copper alloy in the reduction of the oxides of nitrogen in the diesel engine exhaust [27–29]. The alloy used was Monel which includes 65% nickel, 33% copper, and 2% other elements. Their study shows 70% reduction in oxides of nitrogen and it has been concluded that the efficiency of the conversion is dependent upon the bed temperature.

In this paper, a similar study has been conducted with the sole purpose of reducing the consumption of expensive platinum-grade material. Thus, it reduces the cost of the catalytic converters without compromising with its conversion efficiency. For this purpose, the study is strictly based on the material to be used in the monolith substrate. Here, we are using the nickel–copper alloy, i.e., constantan as a catalyst which includes 45% nickel, 55% copper, and no other alloying elements. A device has been fabricated using constantan wire as a newly developed monolith. Experimental study is done to check the percentage conversion of oxides of nitrogen, carbon monoxide, and hydrocarbon.

2 Materials and Methods

The exhaust reducing device is fabricated in two parts; inner monolith of constantan wire mesh and outer casing made of aluminum. The monolith is made of galvanized iron wire net structure of dimension (500 × 160) mm in which constantan wire of 0.5 mm thickness (See Fig. 1a) is weaved throughout. Constantan wire of 200 and 150 mm length is cut and weaved through every alternate hole of the GI wire mesh. The mesh density is kept high to offer maximum surface area for reaction to take place. The monolith is coated with a layer of calcium sulfate hemihydrate to hold the mesh in structure and to enable maximum heating inside the monolith. A 3 mm layer of rubber coating is given over the surface of the monolith to absorb maximum shocks in operating condition.

The outer casing is made of aluminum sheet metal of thickness 2 mm (See Fig. 1b). The structure of the outer casing is kept similar to the presently used catalytic converter. The dimensions of the fabricated device are shown in Fig. 2. The total length

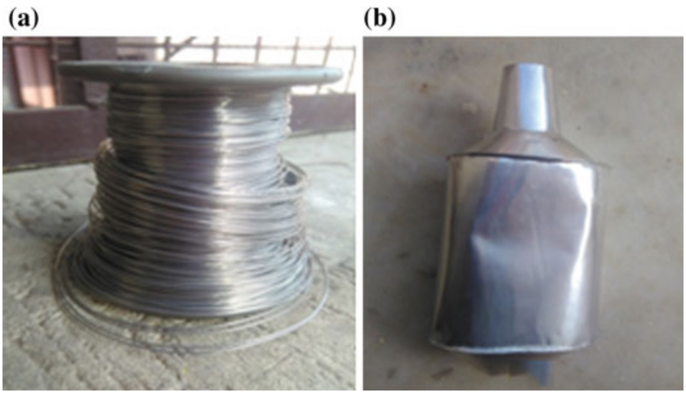

Fig. 1 Image of **a** constantan wire **b** fabricated device

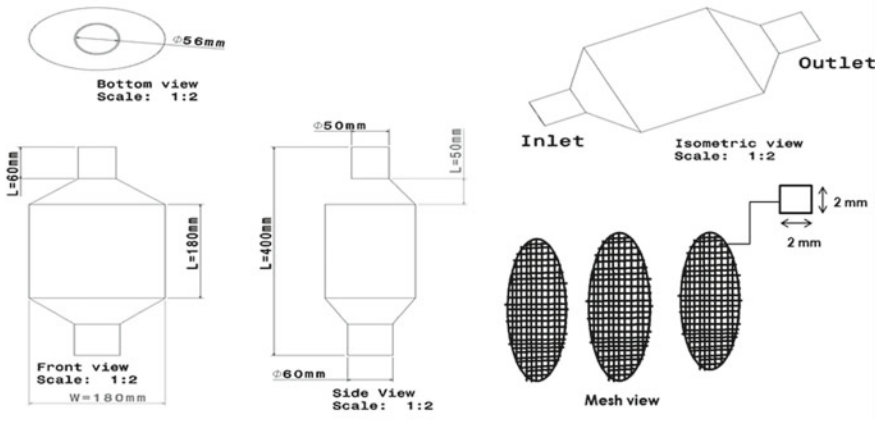

Fig. 2 Drafting of the device showing dimensions

of the device is 400 mm with the inlet and outlet diameters of 56 mm. The mesh view of Fig. 1 shows the arrangement of the constantan wire such that the cross-link arrangement of the wires forms very fine square with the sides of 2 mm.

Here in Fig. 3 point 1 shows the inlet section of the device, and this section is attached to the exhaust pipe of the engine. Point 2 shows the outer aluminum casing of the device. This metal covering supports the inner components and protects the device from any mechanical damage. Point 3 shows the layer of rubber cladding applied below the metallic casing to damp mechanical vibrations. Also, it seals exhaust gases from escaping the wire mesh inside the device. Point 4 shows the layer of calcium sulfate hemihydrate enclosing the wire mesh. This layer provides thermal insulation to the device. Point 5 shows the dense copper–nickel alloy (constantan) wire mesh. This mesh acts as the catalyst for the reaction to occur. Following reaction take place in presence of constantan as catalyst:

$$\mathrm{NO} + \mathrm{CO} \rightarrow \frac{1}{2}\mathrm{N_2} + \mathrm{CO_2} \tag{5}$$

$$\mathrm{C_nH_m} + (2\mathrm{n} + \mathrm{m}/2)\mathrm{NO} \rightarrow (\mathrm{n} + \mathrm{m}/4)\mathrm{N_2} + \mathrm{nCO_2} + \mathrm{m}/2\mathrm{H_2O} \tag{6}$$

$$\mathrm{NO} + \mathrm{H_2} \rightarrow \frac{1}{2}\mathrm{N_2} + \mathrm{H_2O} \tag{7}$$

Point 6 shows the outlet section of the device. This section can either be exposed to the atmosphere or can be attached to the catalytic converter as per the requirements of the user.

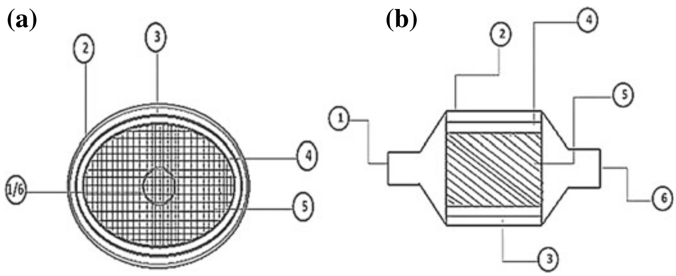

Fig. 3 Schematic diagram of **a** front view **b** side view of the device

3 Experimental Procedure

In order to measure the reduction efficiency of the newly fabricated device with constantan as a monolith, the device is fitted to the exhaust tailpipe of a water-cooled single cylinder direct injection engine. The specifications of the engine are given in Table 1. The experimental schematics are shown in Fig. 4. The NO_x, CO, and HC emissions are measured by AVL DGAS 444 analyzer. The fuel flow is measured with the help of the burette and stopwatch. The device is fitted to the exhaust system and no leakage is verified. The engine is run at a constant 1500 rpm at no load condition for 1 h. At the initial stage, the engine and the device are allowed to get heated up to avoid any cold starting problem. The AVL DGAS 444 analyzer is used first to record the emissions of NO_x, CO, and HC without the device and then the same is recorded with the device attached. All the readings are recorded for 15 min duration and the same is tabulated and compared graphically.

Table 1 Engine specifications

Make	Apex Innovation 240 Pe
No. of cylinder	1
No. of strokes	4
Bore diameter	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer arm length	185 mm
Fuel	Diesel
Power	3.5 kW
Speed	1500 rpm
Compression ratio range	12:1 to 18:1
Injection point variation	0–25 (in degree) BTDC

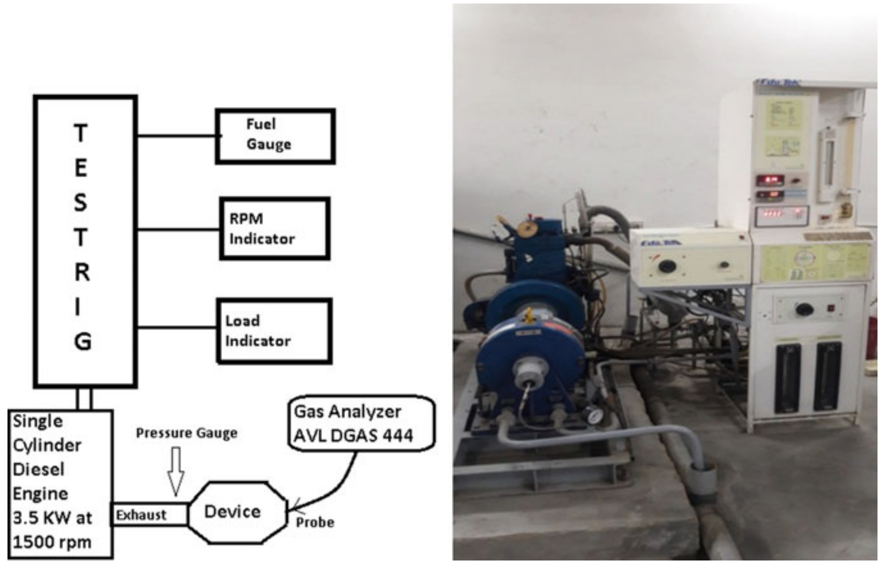

Fig. 4 Schematic diagram of the experimental setup and photograph of the experiment

AVL DGAS 444 Gas Analyzer Calibration. Before performing the emission testing, the gas analyzer is run through several testing procedures to ensure correct functioning. These tests are a prerequisite to its working.

Leak test. The gas in port is covered by the thumb and leak test is run. After 30 s, the leak test confirmation is achieved. In case of any anomaly, the error message is shown on the screen.

Residual Test. Soon after the leak test, residual test is checked. This test is done to ensure complete evacuation of any residual exhaust particles inside the channel of the analyzer. After positive residual test, calibration of the analyzer is required.

IRO Sensor Calibration Test. This test is run to calibrate various sensors in the analyzer like oxygen sensor, etc. with the ambient condition.

Hydrocarbon Residual Test. This test is run to ensure the complete absence of any particulate matter of any hydrocarbon residue inside the analyzer system.

After performing the entire abovementioned test, the AVL DGAS 444 gas analyzer is ready to be used for emission testing. All the parameters are set with respect to ambient conditions.

4 Results and Discussions

Experimental investigations are carried out and variations of exhaust emissions in the form of NO_x, CO, and HC are graphically represented with respect to time factor at a constant 1500 rpm at no load condition.

The conversion efficiency of the device is calculated by the following formula:

$$\frac{\text{Emissions without device} - \text{Emissions with device}}{\text{Emissions without device}} \times 100\%$$

4.1 *Effect of Device on NO_x Reduction*

Emission testing shows a significant reduction in NO_x with the use of the device. All the emissions are recorded with respect to time. At time t = 1 min, the conversion efficiency of the device for NO_x is 76%, which fluctuates till 60% at the end of 15 min and then get stabilized. The increase in conversion efficiency is because with time the device also gets heated up. For the reaction to take place, the device needs to reach its light-off temperature. So as the device reaches its maximum efficiency it gets stabilized. The emissions of NO_x with and without device with respect to time are plotted in Fig. 5.

4.2 *Effect of Device on Hydrocarbon Conversion*

The device shows a significant reduction in emissions of hydrocarbon. The reduction of NO_x starts from 57.45% at time t = 1 min and get stabilized at 35% at the end of 15 min. The emissions of HC with and without device with respect to time are plotted on Fig. 6.

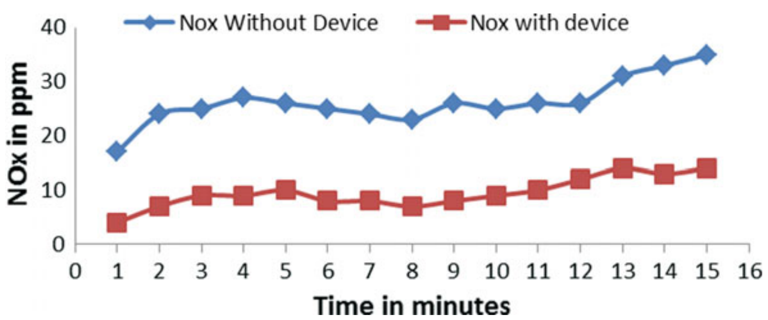

Fig. 5 Variation in NO_x emissions with and without device w.r.t. time in minutes

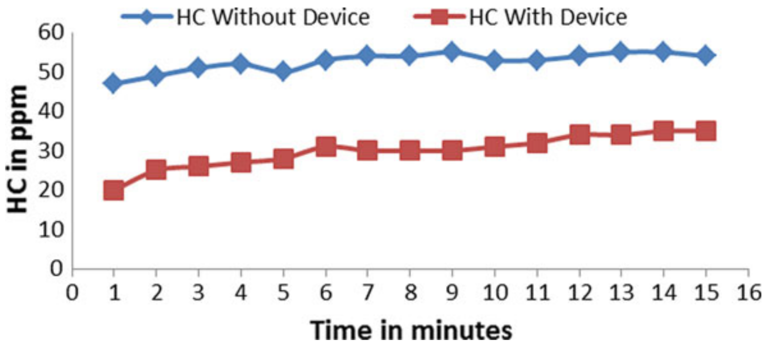

Fig. 6 Variation in HC emissions with and without device w.r.t. time in minute

4.3 Effect of Device for Carbon Monoxide Conversion

The device shows a remarkable reduction in emissions of CO. At the beginning of emissions testing, the oxidation of CO was recorded as 63.33% which undergoes slight fluctuation with time and get stabilized at 60.11% at the end of time $t = 15$ min. The emissions of HC with and without device with respect to time are plotted in Fig. 7.

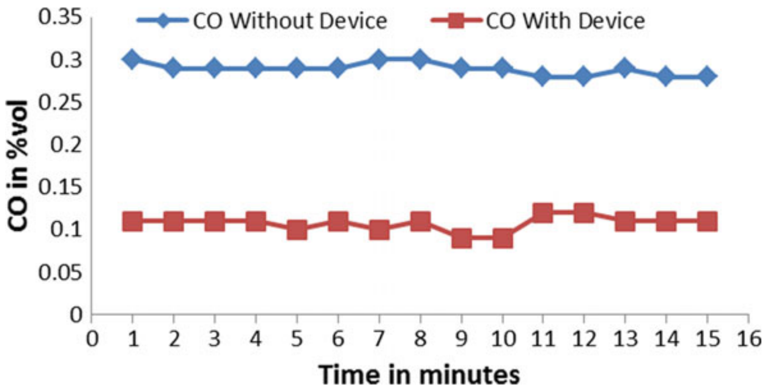

Fig. 7 Variation in CO emissions with and without device w.r.t. time in minutes

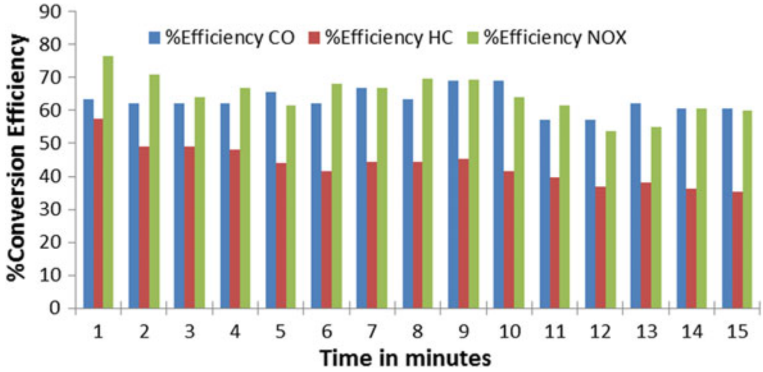

Fig. 8 Comparison of conversion efficiency of CO, HC, and NO_x w.r.t. time

4.4 Comparison of Percentage Conversion Efficiency of the Device

The device shows significant results for NO_x, CO, and HC conversion. Results also show evident fluctuation of emissions with time. Figure 8 represents the percentage conversion efficiency variation for CO, HC, and NO_x, respectively, with time.

5 Conclusion

Based on the results it can be inferred that the device shows significant reduction in exhaust emissions when tested on a single cylinder diesel engine. NO_x, CO, and HC emissions are reduced by 60, 60, and 35% approx, respectively. During experimental investigation, the device generates no back pressure, so the loss in engine efficiency does not come into existence. Further, the cost analysis of the device shows that the manufacturing of the device is cheap. This device can be utilized as a partial replacement or as an add-on with the presently used three-way catalytic convertor. This will ensure less use of the platinum-grade materials like platinum, palladium, and rhodium in the present catalytic convertor with its improved efficiency. Also, this device can be used in other standalone power generating IC engine units where no catalytic converters are used. The above study tries to work on a noble cause of pollution reduction from auto exhausts and shows promising results for future application of it in the automobile market.

References

1. Perry R, Gee IL (1994) Vehicle emissions and effects on air quality : indoors and outdoors, pp 224–236
2. Sharma RC, Sharma N (2014) Environmental impact of automobiles in India, pp 46–49
3. Briggs D (2018) Environmental pollution and the global burden of disease, pp 1–24
4. Guttikunda SK, Jawahar P (2014) Atmospheric emissions and pollution from the coal- Fi red thermal power plants in India. Atmos Environ, e11–e11
5. Ramanathan V, Feng Y (2009) Air pollution, greenhouse gases and climate change: global and regional perspectives. Atmos Environ, 37–50
6. Dasch JM (1992) Nitrous oxide emissions from vehicles 3289
7. Trout BL, Chakraborty AK, Bell AT (2012) Analysis of the thermochemistry of NO_X decomposition over CuZSM-5 based on quantum chemical and statistical mechanical calculations, pp 17582–17592
8. Huang T, Chiang D, Shih C, Lee C, Mao C, Wang B (2015) Promoted decomposition of NO_x. Environ Sci Technol, 3711–3717
9. Miwa K, Mohammadi A, Kidoguchi Y (2001) A study on thermal decomposition of fuels and NO_X formation in diesel combustion using a total gas sampling technique. Int J Engine Res, pp 189–198
10. Klimisch RL, Larson JG (eds) (1975) The catalytic chemistry of nitrogen oxides. Springer US, Boston, MA
11. Yu Y, Li Y, Zhang X, Deng H, He H, Li Y (2015) Promotion effect of H_2 on ethanol oxidation and NO_x reduction with ethanol over Ag/Al_2O_3 catalyst. Environ Sci Technol 49:481–488
12. Chalapathi KS, Murthy CB, Kumar BSP (2014) Development of automobile catalytic converter during last four decades. Int J Res Appl Sci Eng Techn 2(XI):321–333
13. Farrauto RJ, Heck RM (1999) Catalytic converters: state of the art and perspectives. Catal Today, 351–360
14. Mohiuddin AKM, Rahman A (2012) Investigation using simulations for the development of low cost catalytic converter from non-precious metals. Adv Mater Res 445(X):899–904
15. Kalam A, Hassan MH (2011) Design, modification and testing of a catalytic converter for natural gas fueled engines, pp 677–688
16. Kalam MA, Masjuki HH, Redzuan M, Mahlia TMI, Fuad MA, Mohibah M, Halim KH (2009) Development and test of a new catalytic converter for natural gas fuelled engine, pp 467–481
17. Ghodrat M, Shara P, Samali B (2018) Recovery of platinum group metals out of automotive catalytic converters scrap : a review on Australian trends and challenges
18. Teng H, Hsu L, Lai Y, Kung NC (2001) Catalytic reduction of NO with NH_3 over carbons impregnated with Cu and Fe, pp 2369–2374
19. Taylor KC (1984) Automobile catalytic converters
20. Huuhtanen M (2006) Zeolite catalysts in the reduction of NO_x in lean automotive exhaust gas conditions. Behaviour of Catalysts in Activity, DRIFT and TPD Studies
21. Andreas M (2016) Zeolite catalysis. Catalysts 6–118
22. Paramadayalan T, Pant A (2013) Selective catalytic reduction converter design : the effect of ammonia nonuniformity at inlet 30(12):2170–2177
23. Sindhu R, Rao GAP, Murthy KM (2017) Effective reduction of NO_x emissions from diesel engine using split injections. Alexandria Eng J
24. Bera P, Hegde MS (2010) Recent advances in auto exhaust catalysis. J Indian Inst Sci 90:299–395
25. Labhsetwar N, Biniwale RB, Kumar R, Rayalu S, Devotta S (2006) Application of supported Perovskite-type catalysts for vehicular emission control, pp 55–64

26. Chauhan S (2010) J Chem Pharm Res, 602–611
27. Balagurunathanb K, Ganesanc V (1995) Reduction of Nitrogen Oxide emissions using Nickel-Copper alloy catalyst in diesel engines, pp 167–171
28. Leman AM, Afiqah J, Fakhrurrazi R, Dafit F, Supa Z, Rahmad R (2016) Catalytic converter developed by Washcoat of γ-Alumina on Nickel Oxide (Nio) catalyst in FeCrAl substrate for exhaust emission control : a review 1045:1–7
29. Amin CM, Goswami JJ, Rathod PPP (2012) Copper based catalytic converter, pp 1–7