Experimental investigation on reducing agents for catalytic converters of CI engine

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Abstract: High level pollution and emissions arising out of ever-increasing transport vehicles are wreaking a lot of havoc on the environment globally. Stringent emission norms and regulations force the research community across the globe to develop exhaust gas after-treatment systems for effective emission control. Catalytic converters are used to reduce the emissions of hydrocarbon, nitrogen oxides, carbon monoxide and particulate matter. Selective catalytic reduction (SCR) is a system used in IC engines, in which the NOx emission is reduced by injecting a reducing agent in the presence of catalyst. Normally adblue solution is used as the reducing agent for the dissociation of NOx into nitrogen and water. However, it has many drawbacks like NH3 slip, deposit formation and incomplete conversion of NOx. In the present study investigation has been carried out in a CI engine provided with a Vanadium based catalytic converter. Three different reducing agents were used for the dissociation of NOx into nitrogen and water and their effectiveness in controlling the NOx emission has been analyzed and reported.

Keywords: IC engine, NOx emission, SCR, catalyst, Adblue Solution, Formic acid, Glucose

1. Introduction

In all the automobile vehicle engines, catalytic converters are essentially provided to reduce the emissions of hydrocarbon, nitrogen oxides and carbon monoxide. Selective catalytic reduction (SCR) is the system used in IC engines, in which the NOx emission is reduced by injecting a reducing agent in the presence of catalyst [1]. Adblue solution is the most commonly used reducing agent for the dissociation of NOx into nitrogen and water. However, it has many drawbacks like NH3 slip, deposit formation and incomplete conversion of NOx. Active research has been carried out across the globe to come out with cost effective, efficient and environment friendly reducing agents, to be used in catalytic converters for emission control [2]. A catalytic converter (also known as a cat-con) is an engine component that reduces toxic emissions from an internal combustion engine. These devices are now used in almost every vehicle on the road. Since fossil fuels in engines are not fully oxidized due to a lack of oxygen, poisonous by-products are emitted into the atmosphere through the exhaust. The cat-con are thus used to improve the oxidation and reduction mechanisms in order to convert harmful gases like nitric oxides, carbon monoxide, and hydrocarbons into non-harmful gases like nitrogen, carbon dioxide, and water. It has the potential to convert up to 98 percent of toxic exhaust gases into less hazardous gases. It has a metal casing with an artistic honeycomb structure and protective insulating layers on the inside. The honeycomb inside is made up of dainty divider channels that are coated in an aluminum
oxide washcoat [3].

The coating is rendered permeable or porous, which creates a surface zone that allows for further responses. It is made up of precious metals such as platinum, rhodium, and palladium. A single converter uses 4-8 grammes of these priceless metals. SCR is an emissions control technology that is widely used now a days for reducing the NOx emissions produced by internal combustion engines. It generally uses ECU operated injection system for injecting the reducing agent which be in liquid form into the flow of exhaust gases [4]. The source of the reductant is typically urea, also known as Diesel Exhaust Fluid (DEF). This causes a reaction in which nitrogen oxides are converted to N₂, H₂O, and trace quantities of CO₂, all of which are normal components of the air we breathe, and then comes out through vehicle tailpipe. Nitrogen oxide (NOx) reduction reactions can take place in an oxidizing environment, thanks to SCR technology. It’s called "selective" because it uses as a reductant within a catalyst system to minimize NOx levels. The chemical reaction is called "reduction," and DEF is the reducing agent that reacts with NOx to turn the contaminants into environment friendly substances [5, 6]. Zeolite 5A catalyst reduces NO and HC emissions significantly for the waste plastics pyrolyzed oil [7]. SCR with urea solutions reduces NO emissions by 66% for and plastic oil fuelled engines [8, 9].

2. Experimentation
Experiments were carried out in a 5.2 kW single cylinder, four stroke cycle diesel engine provided with an eddy current dynamometer. The photographic view of the test engine is shown in figure 1. An AVL gas analyzer is used in the present investigation for the measurement of CO, HC, CO₂ and NOx concentration in the exhaust gas. A smoke detector is also used to measure the smoke opacity in the exhaust smoke. A probe placed at the tail end of catalytic converter is used to convey the exhaust gas into the gas analyzer for emission measurements. Photographic view of the gas analyzer used is shown in figure 2.

Figure 1. Test engine set
A simple injector and a pump are used to inject the fluids into the exhaust stream. Before injection into the exhaust stream, the volume flow rate of the fluids, were measured and controlled to 135 ml/min. A pipe is used to connect the engine exhaust port and the catalytic converter. A hole of suitable size was drilled in the catalytic converter for the insertion of the injector. Figure 3 shows the photographic view of the injector used in the experimental setup. The test set up comprising of the catalytic converter, injector and the exhaust pipe is shown in figure 4.

Experiments were conducted for five different test conditions namely without catalytic convertor, with the use of conventional catalytic catalytic convertor, catalytic convertor with adblue solution, catalytic convertor with formic acid and that with glucose as reducing agents. Initially the engine was operated without the use of catalytic convertor. The engine was allowed to run at no load condition and after stabilization the readings were noted from the gas analyzer. Then the load is varied with the help of an eddy current dynamometer from no load to full load condition and in each load condition, readings were taken. The above procedure was repeated with the presence of the catalytic convertor, and then with the injection of three different reducing agents sprayed through the injector into the exhaust gas stream. The efficiency of the three different reducing agents in reducing the NOx emission is obtained.
by comparing the readings with those obtained without catalytic convertor (base readings). As NOx emission into the atmosphere is more vulnerable than others, the potential of only NOx emission reduction in the exhaust gas with the three different reducing agents has been analyzed.

![Figure 4. Photographic view of convertor assembly](image)

Reducing agents were shortlisted based on, they should reduce mainly NOx in to nitrogen and oxygen, should have high auto ignition temperature, should be in liquid form as controlling gas is tough, agent itself should not pollute the environment, agent should not form large amount of solid precipitate blocking the flow of exhaust, can be easily stored for long time without losing its efficiency, should be of low cost and abundant.

Formic acid is the simplest carboxylic acid is formic acid, also known as methanoic acid (HCOOH). Formates are esters, and the anion extracted from formic acid. Methanol is used to make formic acid in industries. It is a colorless liquid, pH – 1.5, Odor – pungent, boiling point - 107°C, melting point -20°C, auto ignition temperature - 500°C.

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2\text{HCOOH} + 2 \text{NO} \rightarrow \text{N}_2 + 2 \text{CO}_2 + 2 \text{H}_2\text{O}
\]

Glucose is a kind of sugar and its chemical formula is C₆H₁₂O₆. It comes under monosaccharides. Plants are the main source of glucose production. They use sunlight to produce C₆H₁₂O₆ from H₂O and CO₂. Algae is one of the main sources of glucose. Glucose is the most significant source of energy in all organisms' energy metabolism. Color – It forms colorless mixture with water, pH – 3.5-6, odor – odorless, melting point - 150°C, solubility in water – 909g/L, auto ignition temperature - 700°C.

3. Results and Discussion
3.1 NOx Emission potential
The variation of NOx emission with respect to load for all the five different test conditions is shown in figure 5. The emission is found to increase with load for all the five cases and this increase in value is predominant in the case of without use of catalytic convertor [10]. It is evident from the graph that Glucose has not provided any influence on NOx reduction at all load conditions in comparison with catalytic convertor and the other two reducing agents. Adblue solution is found to produce less NOx at all loads except at full load condition. Maximum NOx reduction has been recorded for formic acid at the full load condition. At full load condition, formic acid emitted 352 ppm of NOx as against 506 ppm with the use of conventional catalytic convertor and 1153 ppm without use of catalytic convertor. In
comparison with the use of conventional catalytic convertors, Adblue solution and formic acid were found to reduce NOx emission considerably at all load conditions. Though Glucose produced NOx emission at par with use of catalytic convertor at full load condition, at all other loads, the emission level is more than that recorded for the case with use of catalytic convertor.

![Figure 5. NOx emission](image)

3.2 NOx reduction with formic acid and adblue solution
It is observed experimentally that out of the three reducing agents tested for NOx reduction potential, Glucose is found useless and only adblue solution and formic acid were very effective in reducing NOx emission at all loads in comparison with the use of conventional catalytic convertor. Figure 6 highlights the variation in percentage of NOx reduction potential of Formic acid and adblue solution with load, keeping the NOx emission without use of catalytic convertor as the reference value.

![Figure 6. Percentage of NOx reduction](image)

It is evident from the graph that at no load condition, Adblue solution exhibited only 34.48% of NOx reduction as against 58.62% exhibited by Formic acid. However at the full load condition, the difference is very marginal and Adblue solution and formic acid exhibited NOx reduction of 57.76% and 69.47% respectively. At all other load conditions, both experienced almost the same NOx reduction percentage.

4. Conclusions
In the present study, investigation has been carried out in a CI engine provided with a Vanadium based catalytic convertor. Three different reducing agents were used for the dissociation of NOx into nitrogen and water and their effectiveness in controlling the NOx emissions have been analyzed and reported.
Finding a suitable reducing agent was a hard task considering high working temperatures and other conditions. After extensive literature review, Adblue solution, Formic acid and Glucose were taken into consideration based on their good reducing ability and high auto ignition temperatures.

Glucose has not produced any remarkable impact on NOx reduction and the other two reducing agents showed remarkable effects in controlling NOx emission in comparison with the use of conventional catalytic convertor. Formic acid showed better results than the standard urea (Adblue) solution which is used commercially. It has witnessed a maximum of 69.47% reduction in NOx emission at full load, in comparison with NOx emission recorded for without use of catalytic convertor.

It is concluded that Formic acid could be a very good reducing agent to be used in catalytic convertors for effective NOx reduction in diesel engine applications.

References

1) S.Premkumar and G.Balaji. “Experimental investigation of HC and CO emission reduction from a diesel engine powered by plastic oil blend using fly ash as catalyst”, Journal of Thermal Analysis and Calorimetry 2021; DOI:10.1007/s10973-020-10541-0.
2) B.Sachuthananthan, G.Balaji and R.L.Krupakaran, “Experimental exploration on NOx diminution by the combined effect of antioxidant additives with SCR in a diesel engine powered by neem biodiesel”, International Journal of Ambient Energy 2020; 41:8; 889-900.
3) G. Balaji, D.Premnath, R.Yuvaraj, Akshdeep Singh Kohli. “Experimental Analysis of Exhaust Emissions Using Catalytic Converter”, IOP Conf. Series: Materials Science and Engineering 2018; 402, 012199.
4) BagusIrawan RM, Purwanto P and Hadiyanto H  Optimum Design of Manganese-Coated Copper Catalytic Converter to Reduce Carbon Monoxide Emissions on Gasoline Motor Procedia Environmental Sciences 2015; 23, 86–92
5) G.Balaji, Utkarsh Arora, Saurav Dasgupta and Siddhant Mund, Individual effects of antioxidant additive and SCR system on the NOx reduction of a CI engine powered by cottonseed oil blend, IOP. Material Research Express 2019; 6, 085540.
6) S.Premkumar and G.Balaji. “Exploration of Zeolite 5A as catalyst in the after treatment system for a CI engine powered by plastic oil blend”, IOP Conf. Series: Materials Science and Engineering 2020; 912, 042028.
7) Balaji Gnanasikamani, Sachuthananthan Bharathy, Suresh Kumar K and Cheralathan Marimuthu. Ecological influence of addition of antioxidant and incorporation of selective catalytic reduction on NO emission in off-road engines powered by waste plastic oil blend. Environmental Progress & Sustainable Energy, 2019; DOI: 10.1002/ep.13383.
8) G.Balaji and M.Cheralathan. Experimental investigation of varying the fuel injection pressure in a direct injection diesel engine fuelled with methyl ester of neem oil. Taylor and Francis. International Journal of Ambient Energy 2017; 38: (4), pp 356-364.
9) G.Balaji and M.Cheralathan. “Experimental reduction of NOx and HC emissions in a CI engine fuelled with methyl ester of neem oil using p-phenylenediamine antioxidant”, Journal of Scientific & Industrial Research 2014; 73, (3), 177-180.
10) G.Balaji and M. Cherlalathan. “Influence of alumina oxide nanoparticles on the performance and emissions in a methyl ester of neem oil fuelled DI diesel engine”. Thermal sciences 2017; 21(1B), 499-510.