

Emission Control Diesel Power Plant for Reducing Oxides of Nitrogen through Selective Catalytic Reduction Method using Ammonia

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Abstract

Background/Objectives: The major pollutant that comes out from engine exhaust of Diesel Power Plant (DPP) is Nitrogen Oxide (NO_x) as well as Sulphur oxides (SO_x). Since NO_x concentration level is higher it affects our environment to great extent. Our main objective of our project is to reduce NO_x concentration level to lower rate of parts per million (ppm). **Methods/Statistical Analysis:** The NO_x concentration level is higher in DPP as they didn't install any NO_x control methods. We suggested using Selective Catalytic Reduction (SCR) method for controlling NO_x emission. Ammonia (NH_3) is making use of reagent in SCR technique and it is inject to the exhaust stream. **Findings:** NH_3 reacts with NO_x present in the exhaust and it is converted into Nitrogen (N_2) and water (H_2O). It is proposed that, if SCR system is installed in Diesel Power Plant, NO_x concentration level is expected to reduce from 1100 ppm to 132 ppm. **Application/Improvements:** If The proposed system is implemented successfully in the power plant, then NO_x concentration level could be reduced to approximately 132ppm (<2 g / kWh).

Keywords: Diesel Power Plant, Exhaust Gas, Pollution Free Environmental, Selective Catalytic Reduction System

1. Introduction

The investigation of exhaust emission is a major role in environmental science because the increases of the petroleum based power plants and transportation vehicles in the modern living community in the world. At the same time the harmful gases like Hydrogen Oxide (HO) and Carbon Monoxide (CO) come out from the exhaust of I.C. engine should be minimized to product the green environment and safe to the human healthy life.

Nitrates that form in the atmosphere from Nitrogen Oxide (NO_x) compounds are captured as small particles or as dissolved acid in rain or mist. The nitrates that are deposited in soils can affect the pH of the soils and the uptake of nutrients. Nitrates that reach surface waters such as rivers and lakes increase the nitrogen content of the water. This nitrification process affects the growth of algae and

other organisms that can affect aquatic life. The control of NO_x will be one of the important elements in the development of controls of PM2.5. NO_x are the main precursors contributing to the formation of these very small particles in the atmosphere. Nitrates, compounds that form from NO_x , are one of the constituents of PM2.5 and one of the groups of chemicals that are believed to cause adverse health effects. NO_x affects humans at extreme level.

Apprehensive issue of Greenhouse Gases (GHG) emission from I.C. engine exhaust gas and it is interrelated with climatic reforms. When utilizing coconut oil as a fuel of I. C. engine that exhaust emission gives lesser CO, HC and NO and superior thermal efficiency compare to the diesel fuel^{1,2}. The use of coconut oil as an alternative fuel in direct injection diesel engine. It has been reported that the peak thermal efficiency for coconut oil was 28.67% and for diesel. It was 32.51%. It has also been concluded

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that the smoke, CO, HC and NO emissions were lesser than diesel emissions while the exhaust gas temperature was superior than diesel¹³. The specific fuel consumption as well as brake thermal efficiency increases also decreasing exhaust emission considerably due to the blends of Tamanu Methyl Ester and DiEthyl Ether with diesel¹⁴.

Combination of canola oil-hazelnut soap stock biodiesel diesel blends like 5% (B5) and 10% (B10) with diesel blend which gives the less CO and more NO when burning¹². The effect of burning EGR along with JBD100 on emission parameters found out to be high on both 20% and 25% EGR at high load. For both fuel at high load NO emission found to be under reduction zone^{3,4,5}. When 60% of vegetable oil at inferior viscosity mixed through diesel blend which decrease the CO and HC level when burning. Jatropa Biodiesel for NO reduction found that for 15% EGR and JBD25+D75 composition NO get reduced and thermal efficiency is increased by 1.12%⁶. CO₂ emissions from the fossil liquid fuel in thermo-electric power plant I.C. engine for workout factors of emission in favor of electric power production⁷. Use of jatropa increases NO_x emission at low EGR condition and further decreases significantly at High EGR said 20%. HC emission reduction can be seen at 15% EGR afterwards increased due to high EGR rate⁸. The effect of using unleaded gasoline and additives blends (Ethanol blends and Isobutanol-Ethanol blends) on spark ignition engine (SI engine) performance and exhaust emission. The engine used for experimental purpose is Bajaj engine of 5.2 kW (7.2hp). A new multi liquid fuel mixing system has been developed for perfect mixing and hence found better for investigating effects of various ethanol fuel blends (E10,E20,E30) and isobutanol and ethanol-gasoline mixture. They found that the CO and HC emissions concentrations in the engine exhaust decreases while the NO_x concentration increases. The addition of 5% isobutanol and 10% ethanol to gasoline gave the best results for all measured parameters at all engine torque values⁹.

The performance and emissions parameters with cold EGR and Hot EGR and observed that thermal efficiency increases with lower EGR Rate and get lower by 0.9%. At 20% EGR at 45N-M torque. But in case of Cold EGR NO_x formation gets reduced by 64% but thermal efficiency decreases by 1.12% also increases at high load and High EGR say 15%¹⁰. The performance analysis of single cylinder, air cooled diesel engine using fish oil biodiesel (B20) with diesel. The brake specific fuel consumptions is higher for vegetable oil when match up to diesel. They resulted that 20 % of linseed oil, methyl ester blend has

best that enhanced the thermal efficiency and condensed the smoke density¹¹.

The main objective of our project is to reduce NO_x concentration level to lower rate of ppm. The NO_x concentration level is higher in DPP as they didn't install any NO_x control methods. We suggested using Selective Catalytic Reduction (SCR) method for controlling NO_x emission. Ammonia (NH₃) is used like a reagent which inject in to the exhaust gas stream.

2. Emissions in Diesel Power Plant

2.1 NO_x Emission (Oxides of Nitrogen)

NO_x are involved in many regulatory areas and, although it is not the primary pollutant of concern in many of these regulatory areas, it plays an important role. These programs are the basis for controlling NO_x emissions. NO_x plays a role in the regulatory programs of acid rain, forest damage, ozone non-attainment, NO₂ health effects, fine PM and Visibility.

The compounds comprise the category of NO_x are oxide of nitric, dioxide of nitrogen, oxide of nitrous, trioxide of dinitrogen, tetroxide of dinitrogen and dinitrogenpentoxide. Addition to these six compounds, nitrate radicals are also known to occur in the atmosphere. Nitric oxide and nitrogen dioxide is the two main pollutants of concern. Over 90% of the NO_x produce by resource of the stationary combustion. NO₂ is formed in the atmosphere from the NO that is released from the stack. Less than 5% of the NO_x released NO₂ by the resources of stationary combustion. Although emitted in small quantities, it migrates to the stratosphere and participates in depletion of the stratospheric ozone layer. It also was once thought to be a problem from coal combustion, but current data indicates that it is emitted at levels below 5 ppm. N₂O is formed in the early stages of combustion, but is subsequently destroyed rapidly at high temperatures. For that reason, N₂O is not an emission of concern from conventional power plants and conventional fossil fuel-fired sources.

Emissions of N₂O are more of a concern from low temperature processes such as fluidized bed combustion, where the destruction of N₂O is much slower. Emissions from these low temperature operations can range from 70 to 200 ppm. There is also concern about possible formation of N₂O from flue gas treatment systems based on Selective Catalytic Reduction (SCR). The use of certain materials such as cyanuric acid and urea can contribute to the formation of N₂O.

2.2 NO_x Formation Mechanisms in Combustion Process

During combustion there are three complex chemical reactions occur from NO_x. They are thermal based NO_x; fuel based NO_x, and prompt (or) rapid NO_x.

2.2.1 Thermal based NO_x

In thermal based NO_x formation, NO_x formed by reaction of N₂ from the combustion air with reactants such as O and OH radicals and molecular NO₂. Thermal based NO_x be the primary based NO from stationary combustion sources. The formation of NO_x through the main O_x mechanism has a slow reaction time and, therefore, requires time for equilibrium to be reached. The formation of thermal NO_x peaks between 1900°C and 2000°C. Because this is the temperature range in which most stationary combustion sources operate, it is easy to understand that thermal NO_x is the main mechanism by which NO_x is formed in combustion processes.

Chemical reactions during NO_x formation:



2.2.2 Fuel based NO_x

The amount of NO_x formed from this mechanism is a function of the fuel being combusted. Natural gas has no fuel nitrogen, and therefore no NO_x is formed by this formation mechanism from the combustion of natural gas. The amount of NO_x formed by the fuel NO_x mechanism in the combustion of fuel oil depends on the type of oil being burned. Heavy oil has tend to have higher nitrogen content than light oils such as residential heating oil. The fuel NO_x reaction mechanism is of most concern when coal is being burned.

2.3 Prompt (or) Rapid NO_x

Prompt NO_x, the third formation mechanism, forms NO_x by converting molecular nitrogen to NO via intermediate products. This reaction occurs in the early phase in the flame front with hydro carbons. Of the three formation mechanisms, prompt NO_x constitutes the smallest source of NO_x. This mechanism has the greatest impact in fuel-rich combustion zones (such as those present in gas turbines) and low temperature combustion processes. The degree of conversion depends on the stoichiometric conditions and temperature.

3. Methodology for NO_x Reduction

The method we have chosen to reduce NO_x emission is Selective Catalytic Reduction (SCR) which applies Ammonia (NH₃) like reagent for reducing NO_x. Ammonia is a colorless non-flammable liquefied gas. SCR is the suitable process for decreasing the emission with cost-effective as well as fuel-efficient manner. It could able to decrease NO_x emission up to 90% simultaneously dropping HC along with CO emissions near 50-90% furthermore PM emissions near 30-50% percent. In order to obtain better emission drop in PM, SCR method could able to mix among diesel. NO_x could be rehabilitated in catalyst with ammonia into nitrogen along with water.

Presently, Toxicity of the reagent is the majority serious problem intrinsic with this technique in the marine environment. Capital investment, operational cost and space requirement are also severe difficulties for implementing this process. Conversely, we recompense up to 95% decrease in NO_x. Now a day's many researchers are doing more concentration with the intention to create in this technique practically in each and every one respect possible.

4. Selective Catalytic Converter (SCR)

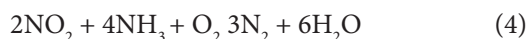
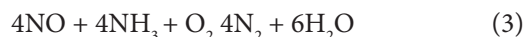
4.1 Definition of SCR

SCR is the process by which oxides of nitrogen (NO_x) contained in diesel exhaust is reduced to nitrogen (N₂) as well as water (H₂O). Selective Catalytic Reduction means, Selective is the targets NO_x in diesel exhaust, Catalytic is requires a catalyst and Reduction is the NO_x is reduced to nitrogen (N₂).

4.2 Operating Principle of SCR

Burning exhaust stream come out from ignition process is cooled from 288°C to 427°C by heat exchanger in boiler. With the purpose of uniform mixing earlier in the catalyst, bed downstream in the economizer, ammonia containing stream are injected via sequence of nozzles prearranged in grid. Ammonia is reducing the nitrogen oxides into nitrogen as well as water steam on catalyst surface in complex set of high temperature and heterogeneous gas phase reactions. The overflow stream which leaves from SCR contains unreacted NO_x and little amount of ammonia. Ammonia (NH₃) emissions are commonly termed as ammonia slip.

Ammonia slip is reagent that has passed through the catalyst without participating in chemical reactions.



These reactions summarize result of a number of separate reactions on the SCR catalyst surface. The activation energies for the above reaction processes are greatly reduced with the use of the catalyst. The maximum rate of conversion for above reactions occurs at 650°F to 750°F in the presence of a catalyst, compared with 1,600°F to 1,900°F without a catalyst. Therefore, the SCR system is installed at a location downstream of the boiler furnace and some of the boiler heat exchange equipment. The introduction of a catalyst also allows undesirable side reactions to occur. For instance, a small portion of sulfur dioxide (SO_2) in the flue gas may be oxidized into sulfur trioxide (SO_3)



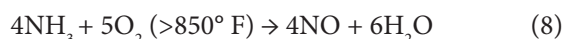
SO_3 from the above reaction can then react with ammonia. Consequently ammonium bisulfate (NH_4HSO_4) and ammonium sulfate ($[(\text{NH}_4)_2\text{SO}_4]$) can form



Ammonium sulfate compounds are capable of corroding and plugging downstream equipment. NH_4HSO_4 and $(\text{NH}_4)_2\text{SO}_4$ form sticky deposits, which can restrict gas flow and result in very expensive unscheduled maintenance. The corrosive nature of NH_4HSO_4 can damage downstream equipment, such as the air preheater. To keep away from this problem among NH_4HSO_4 , SCR system has to activate greater than the temperature during compound form. Catalysts used on coal-fired boilers have been formulated to minimize the generation of SO_3 .

$(\text{NH}_4)_2\text{SO}_4$ homogeneously and heterogeneously nucleates to form fine particulate matter. These reactions are often indicated by plume formation when the flue gases enter the atmosphere. Catalyst composites dictate the high end of the operating temperature range. Presently available catalysts that operate at temperatures greater than 850° F may actually create NOx with NH_3 reactions on the catalyst surface.

NH_3 is oxidized to form NO:



The range of NO_x efficiency reduction from 50% to 90% are possible during the situation are get together the quantity of catalyst is enough, good condition, flow of sufficient ammonia reagent. The sufficient supply of the ammonia across stream with moderate-to-high inlet NO_x levels, reduction efficiencies of 70% to 90% can be sustained, provided that those conditions are met.

4.3 SCR Mechanism

The SCR Chemical reaction is shown in Figure 1.

When the exhaust comes out at 450°C the urea injected to exhaust gas the heat from the exhaust reacts with urea to form Ammonia (NH_3). The Ammonia formed further react by means of NO_x present in exhaust stream to generate Nitrogen and Water. The excess Ammonia which unreacted with NO_x is said to be ammonia slip. The ammonia slip could be reducing by maintaining ammonia injection below 850°F.

5. Ammonia Reagent

5.1 Ammonia Characteristics

The structure of ammonia is shown in Figure 2.

Normally ammonia gets boil at -33.34°C with a pressure of one atmosphere, therefore the it should be accumulated under high pressure as well as low temperature places. Ammonia hydroxide otherwise called domestic ammonia is a resolution of NH_3 in water. The absorption of such solution is calculated in units of the density, with 26° degrees about 30% of weight at 15.5°C being characteristic of high-attention business product.

5.2 Ammonia Feed Requirements

NO is the dominant form of the NO_x in the flue gas, provides the main reaction involved for NOx removal. This reaction indicates that a theoretical $\text{NH}_3:\text{NO}_x$ molar ratio of 1.0:1.0 is necessary for NO_x removal. Actual feed

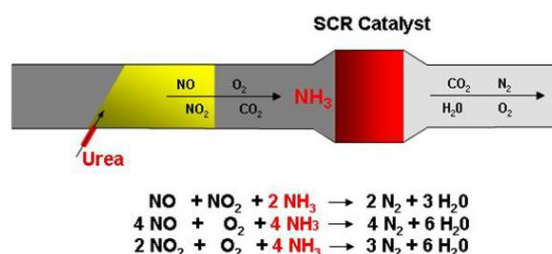


Figure 1. Chemical reactions takes place in SCR.

requirements differ because of factors such as imperfect mixing, incomplete catalyst surface contact, and limited residence time. A NO_x reduction of 90% is achievable with a molar ratio of 1.0:1.0 to 1.05:1.00. However, unacceptable ammonia slip of >20 ppm can result at this molar ratio. Figure 3 displays the ammonia feed rates associated with NO_x reduction efficiencies.

Ammonia is typically injected at ratios about 0.85:1.00³ to 0.90:1.00⁶ to maintain low ammonia slip levels. This means that approximately 0.9 Moles of ammonia is required for each mole of NO_x that necessity to accomplish emission control.

6. Results and Discussion

6.1 Results in Calculation of Ammonia Feed Required Per Day

6.1.1 Calculation of the Pound Moles of Gas

= (Flow rate of exhaust gas in SCFM) $\times$ (1lb mole/molar volume of NO_x in SCF).

$$= (500000 \text{ scf/min}) \times (1 \text{ lb mole}/385.3 \text{ scf}).$$

$$= 1297.69 \text{ lb moles gas min.}$$

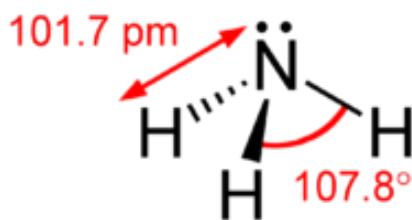


Figure 2. Ammonia structure.

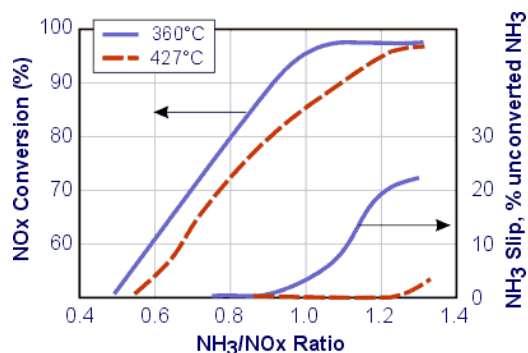


Figure 3. Graph for NO_x versus NH_3/NO_x ratio.

6.1.2 Calculation of the Pound Moles of NO_x at Uncontrolled Conditions

= (NO_x emission rate in lb moles/1lb moles gas) $\times$ (pound moles of gas).

$$= (0.0011 \text{ lb moles of } \text{NO}_x / 1 \text{ lb moles gas}) \times (1297.69 \text{ lb moles gas/min}).$$

$$= 1.4275 \text{ lb moles } \text{NO}_x / \text{min.}$$

6.1.3 Calculation of the Pound Moles of NO_x to be Reduced

= (Percentage reduction in NO_x rate) $\times$ (pound moles of NO_x at uncontrolled level).

$$= 0.7 \times 1.4275 \text{ lb moles } \text{NO}_x / \text{min.}$$

$$= 0.9992 \text{ lb moles } \text{NO}_x / \text{min.}$$

6.1.4 Calculation of the Pound Moles of NH_3 Required

= (0.9 lb moles NH_3 /1lb moles NO_x) $\times$ (pound moles of NO_x to be reduced).

$$= (0.9 \text{ lb moles } \text{NH}_3 / 1 \text{ lb moles } \text{NO}_x) \times (0.9992 \text{ lb moles } \text{NO}_x / \text{min}).$$

$$= 0.8993 \text{ lb moles } \text{NH}_3 / \text{min.}$$

6.1.5 Calculation of the NH_3 Feed Per Day

= (pound moles of NH_3 required) $\times$ (molecular weight of NH_3 in lbmoles/1lb mole of NH_3) $\times$ (1440min/day).

$$= (0.8993 \text{ lb moles } \text{NH}_3 / \text{min}) \times (17 \text{ lb moles} / 1 \text{ lb moles } \text{NH}_3) \times (1440 \text{ min/day}).$$

$$= 22014.85 \text{ lb moles } \text{NH}_3 / \text{day.}$$

6.2 Stoichiometric Ratio (NH_3/NO_x) Ratio Calculation

6.2.1 Calculation of Moles of Ammonia Fed to the System

= (NH_3 feed rate in lb moles/hr) $\times$ (1lb moles NH_3 /molecular weight of NH_3 in lb moles).

$$= (917.28 \text{ lb moles } \text{NH}_3 / \text{hr}) \times (1 \text{ lb moles } \text{NH}_3 / 17 \text{ lb moles } \text{NH}_3).$$

$$= 53.95 \text{ lb moles } \text{NH}_3 / \text{hr.}$$

6.2.2 Calculation of Moles of NO_x Entering the System

= (Flow rate of exhaust gas in SCFM) $\times$ (60 min/hr) $\times$ (1lb mole gas / molar volume of NO_x in SCF) $\times$ (inlet NO_x concentration in lb moles).

$$= (500000 \text{ scf/min}) \times (60 \text{ min/hr}) \times (1 \text{ lb mole}/385.3 \text{ scf}) \times (0.00137 \text{ lb moles NO}_x/1 \text{ lb moles gas}).$$

$$= 62.77 \text{ lb moles NO}_x/\text{hr}.$$

6.2.3 Calculation of Stoichiometric Ratio [(NH₃/NO_x) ratio]

$$= (\text{moles of NH}_3 \text{ fed to system}/\text{moles of NO}_x \text{ entering system}).$$

$$= \{(53.95 \text{ lb moles NH}_3/\text{hr})/(62.77 \text{ lb moles NO}_x/\text{hr})\}.$$

$$= 0.859.$$

$$= 0.86(\text{approximately}).$$

Therefore Stoichiometric ratio = 0.86

6.3 Calculation of Utilization Ratio

6.3.1 Calculation of Moles of Ammonia Fed to the System

$$= (\text{NH}_3 \text{ feed rate in lb moles/hr}) \times (1 \text{ lb moles NH}_3/\text{molecular weight of NH}_3 \text{ in lb moles}).$$

$$= (917.28 \text{ lb moles NH}_3/\text{hr}) \times (1 \text{ lb moles NH}_3/17 \text{ lb moles NH}_3).$$

$$= 53.95 \text{ lb moles NH}_3/\text{hr}.$$

6.3.2 Calculation of Moles of NO_x Reacted

$$= (\text{Flow rate of exhaust gas in SCFM}) \times (60 \text{ min/hr}) \times (1 \text{ lb mole gas}/\text{molar volume of NO}_x \text{ in SCF}) \times \{(\text{inlet NO}_x \text{ concentration in lb moles} - \text{outlet NO}_x \text{ concentration in lb moles})/1 \text{ lb mole gas}\}.$$

$$= (500000 \text{ scf/min}) \times (60 \text{ min/hr}) \times (1 \text{ lb mole}/385.3 \text{ scf}) \times \{(0.00137 - 0.0011) \text{ lb moles NO}_x/1 \text{ lb moles gas}\}.$$

$$= 21.02 \text{ lb moles NO}_x/\text{hr}.$$

6.3.3 Calculation of Utilization Ratio

$$= (\text{moles of NO}_x \text{ reacted}/\text{moles of ammonia fed to system}).$$

$$= \{(21.02 \text{ lb moles NO}_x/\text{hr})/(53.95 \text{ lb moles NH}_3/\text{hr})\}.$$

$$= 0.38.$$

Therefore Utilization ratio = 0.38

While the ammonia is injecting to the exhaust gas at temperature below 850°C NO_x present in the exhaust stream will be converted into nitrogen (N₂) and water (H₂O). The temperature is very important factor in this system because above 850°C ammonia slip will occur and this excess ammonia at this temperature reacts with available oxygen to form NO_x again.

7. Conclusion

NO_x concentration rate in this power plant before using this Ammonia injection system is 1100ppm. If this system is successfully implemented in the power plant, then NO_x concentration level can be reduced to approximately 132ppm (<2 g/kWh). The results are encouraging and proposed method is well suited for pollution free environment.

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