# Solid Selective Catalytic Reduction: A Promising Approach towards Reduction of NO$_x$ Emission from Exhaust of CI Engines

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## ABSTRACT

The rising rate of pollution in urban areas has become a worldwide concern in recent years. Diesel engines are considered one of the largest contributors to environmental pollution caused by exhaust emissions, and they are responsible for several health problems as well. Diesel engines contain carbon monoxide, carbon dioxide, unburned hydrocarbons, and oxides of nitrogen. The reduction of Nitric oxides (NOx) emission from diesel engine exhaust is currently being researched by automotive manufacturers. After much research, selective catalytic reduction (SCR) technology was discovered to be effective in reducing nitrogen oxide emission from diesel engine exhaust. This paper is an attempt to explore the problems associated with the use of selective catalytic reduction (SCR) and compares selective catalytic reduction (SCR) with the latest technology named solid selective catalytic reduction (SSCR) for efficient reduction of NOx emission from the exhaust of diesel engines. The issue of contamination, malfunctioning, and freezing of diesel exhaust fluid (DEF) at low temperatures are the major problems associated with the application of SCR. It is observed that by controlling the quantity of ammonia slip, SSCR can give better performance in the reduction of NOx emission from the exhaust of diesel engines.

## INTRODUCTION

There is no doubt today that air pollution is a global public health emergency. This is a problem that almost every country is dealing with. Faced with the hazard of deteriorating air composition, many countries over the years adapted to technology and strategies to counter the crisis. The seriousness of the issue has (SSCR) been proven by environmental change as a result of a global temperature increase. Air quality issues related to nitrogen oxides and ozone are of significant concern in the United States, Europe, China, and many other locations (Erickson et al. 2020). Transport is the main sector which causes environmental pollution and climate change. Owing to the rapid increase of motor vehicles and very limited use of emission control technologies, transport emerges as the largest source of urban air pollution, which is an important public health problem in most cities of the developing world. Emissions from transport, and especially motor vehicles, add considerably to the levels of greenhouse gases in the atmosphere, being a significant contributor to global warming. Studies have demonstrated that exposure to diesel exhaust gas causes harm to lungs and respiratory issues, and there is strong evidence that diesel discharges cause malignancy in people (Sydbom et al. 2001, Solomon & Balmes 2003, Lewtas 2007). The fumes

of diesel engines contain unburned hydrocarbons (UHC), particulate contaminants, and nitrogen oxides, all of which are responsible for air pollution. The percentage of fumes outflows from diesel motors is shown in Fig. 1

It is clear from Fig.1 that diesel engine exhaust contains a major portion of nitrogen (67%), whereas CO$_2$ (12%), H$_2$O (11%), and oxygen (9%) remain in moderate quantity. Carbon monoxide, hydrocarbons, particulate matter, oxides of nitrogen, and sulfur dioxide (SO$_2$) remain in very little quantity but represent the most hazardous components of diesel engine exhaust which are highly responsible for disturbing the balance of the environment.

Recent studies have shown that particulate matter emissions and outdoor fine particulates were responsible for 7.6% of the deaths (4.2 million people) globally in 2015 (Kurien et al. 2019). Diverse pretreatment and post-treatment headways have been grasped to decrease exhaust radiations. Exhaust emissions from diesel engines pose a serious threat to the environment and human health. The combined application of pre-treatment and post-treatment techniques is the only solution to reduce these emissions. Pre-treatment techniques include engine modifications like combustion cylinder alteration, injection timing retard, exhaust gas recirculation, fuel injection strategies, and so on (Kurien & Srivastava 2018),
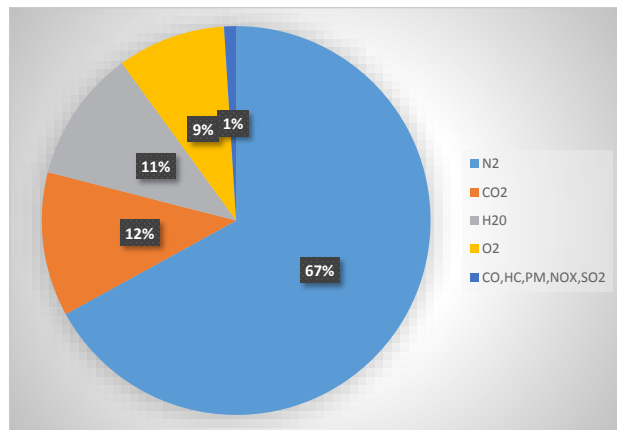
Fig. 1: Composition of diesel engine exhaust (Reşitoǐlu et al. 2015).

Regardless, they are still insufficient to minimize nitrogen oxides emission from the exhaust of diesel engines, which is the most difficult task in reducing hazards. Long-term ambient air pollution exposure was reported to increase all-cause mortality Air pollution is the cause and aggravating factor of many respiratory diseases like chronic obstructive pulmonary disease, asthma, pneumonia, and lung cancer. The presence of a large amount of NOx in the atmosphere causes a destructive deluge and the formation of smoky clouds. Air pollution in the form of Nitrogen oxides (NOx) can harm the ozone layer which protects the surface of the Earth from harmful radiation. Aside from the harmful effects on the environment, these oxides have a significant impact on human health (Yan et al. 2014). Due to the above realities, the Euro-VI emission standards specifically noted that a "considerable reduction in oxides of nitrogen emissions from diesel vehicles is necessary to improve air quality and comply with limit values for air pollution. The move from Euro V to Euro VI saw a large reduction in the NOX emission limit, from 2.0 g.kWh$^{-1}$ to 0.4 g/kWh g.kWh$^{-1}$ in steady-state testing, and from 2.0 g.kWh$^{-1}$ to 0.46 g.kWh$^{-1}$ in transient testing, or reductions of 80% and 77% respectively (Williams & Minjares 2016).

A comparison of emission norms in EURO-V & EURO-VI is shown in Table 1 which clearly indicates the necessity of DPF and SCR in diesel engines. The NOx

Table 1: Requirements of components for EURO -V and EURO-VI norms (Williams & Minjares 2016).

| EURO-V | EURO-VI |
|---|---|
| • High fuel injection pressure. <br> • Redesigns to the combustion chamber. <br> • NOx is controlled mainly by SCR vanadium-based systems. <br> • EGR is offered by some manufacturers and mainly for small trucks. | • DPFs required for EURO-VI compliance with PM and PN standards. <br> • SCR catalyst changes from vanadium to zeolite. <br> • EGR is no longer offered. |

reduction efficiency must be greater than 95% as per the EURO-VI discharge standards, and the ammonia slip must be less than 10ppm. In the United States and Europe, SSCR technology is being adopted in big diesel vehicles, which is both practical and cost-effective.

For the reduction of NOx, various after-treatment technologies such as selective catalytic reduction (SCR), lean NOx trap (LNT), and SCR channel are used, however, the conversion efficiency of NOx could surpass 75% (Praveena & Martin 2018). Exhaust gas recirculation (EGR) is an emission control technology allowing significant NOx emission reductions from most types of diesel engines. However, it cannot achieve a high NOx reduction efficiency that meets existing discharge standards, particularly, in heavy vehicles. Likewise, because of the decrease of temperature in the chamber, this technology increase hydrocarbon (HC) and carbon dioxide ($CO_2$) emanations (Bauner et al. 2009). In Diesel engines, the fuel type, engine adjustment, and design affect the content of hydrocarbons. Besides, HC emissions in the exhaust gas depend on irregular operating conditions. High levels of the instantaneous change in engine speed, untidy injection, excessive nozzle cavity volumes, and injector needle bounce can cause significant quantities of unburned fuel to pass into the exhaust (Payri et al. 2009). Despite the fact that SCR has shown promising results in reducing nitrogen oxides, it is not without its disadvantages. Some nitrogen oxides remain unreduced when fluid urea is used as a decreasing agent, which is known as urea slip. This problem arises due to the fact that the catalyst's ability to change state is reduced at low temperatures. Catalyst efficiency is highest when the temperature of the fumes is between 200$^{o}$C to 400$^{o}$C (Ma et al. 2019). When functioning at these temperatures, the catalyst chamber should be filled on a regular basis, usually, before the fuel chamber is emptied (Lacin et al. 2011). Urea-based selective catalytic reduction (SCR) of nitric oxides (NOx) is a key technology for heavy-duty diesel engines to achieve the increasingly stringent NOx emission standards. The aqueous urea injection control is critical for urea-SCR systems to achieve high NOx conversion efficiency while restricting the tailpipe ammonia (NH3) slip. For Euro VI emission regulation, an advanced control strategy is essential for SCR systems since its NOx emission limits are tighter and test procedures are more stringent compared to Euro IV and Euro V. The complex chemical kinetics of the SCR process has motivated model-based control design approaches. However, the model is too complex to allow real-time implementation. Therefore, it is very important to have a reduced-order model for the SCR control system. (Wang et al. 2018).

**Urea SCR**

Urea SCR is one of the most effective NOx reduction tech-

niques, capable of converting around 95% of nitrogen oxides. It can work effectively at a temperature of 200°C. The exhaust after-treatment devices that are applied to vehicles are Diesel Oxidation Catalysts (DOC), Diesel Particulate Filters (DPF), and Selective Catalytic Reduction (SCR) catalysts. The carbon component includes elemental carbon, total carbon, organic carbon, ions, and water-soluble organic carbon. The installation of retrofits such as Diesel oxidation catalyst (DOC), diesel particulate filter (DPF), and Selective catalytic reduction (SCR) is one of the most effective ways for reducing particulate emissions. The installation of retrofits reduced PM mass emissions by over 90% in cruise and 95% of the fumes from the exhaust of diesel engines (Biswas et al. 2009). Penetration of soot on the wall results in a reduction of deNOx efficiency of the SCR system(Johnson 2016). Most particulate matters (PM) resulted from incomplete combustion of the hydrocarbons in the fuel and lube oil. In an experimental study, it is reported that PM consists of elemental carbon (31%), sulfates and moisture (14%), unburnt fuel (7%), unburnt lubricating oil (40%), and remaining may be metals and other substances (Agarwal 2007). The use of a diesel particulate filter (DPF) reduces elemental carbon by trapping particulates effectively. The amount of organic carbon can be reduced by using catalysts, which oxidize hydrocarbons and reduce the amount of water-soluble organic carbon. The increased amount of sulfate nanoparticles in the DPF manufactured vehicle is caused by a decrease in residue particulate size (Biswas et al. 2009)

Vehicles equipped with catalyzed DPF and urea SCR had 99.9% and 90% efficiency, respectively, in reducing particulate matter. The DPF plasma-assisted burner successfully decreases particulate amount over the whole particle size range (Lee et al. 2015). The Continuously Regenerating Trap (CRT) has been developed to enable diesel engines to meet the proposed future legislation. This passive filter system combines an oxidation catalyst with a Diesel Particulate Filter (DPF); the filter traps the PM and the oxidation catalyst generates NO$_2$ which combusts the trapped PM at substantially lower temperatures than is possible using oxygen. This combines the CRTTM with SCR (Selective Catalytic Reduction) technology and enables very high simultaneous conversions of CO, HC, PM, and NOx to be achieved (Allansson et al. 2000).

The DOC+CDPF+SCR retrofit was proved a feasible and effective measurement in terms of reducing particulate emissions and NOx simultaneously for the in-use engine. The usage of these retrofits has no effect on fuel consumption or engine power (Zhang et al. 2018). These filters can reduce more than 90% of the particulate matter. At the same time, the particulate size is also reduced (Mamakos et al., 2013).
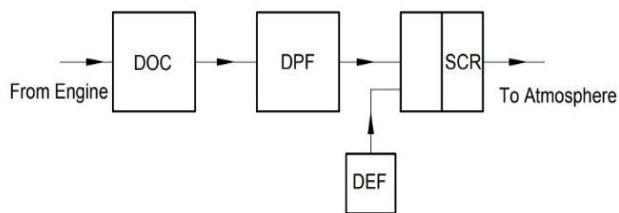


Fig. 2: Schematic diagram of urea SCR (Zhang et al. 2018).

A schematic diagram of urea SCR is shown in Fig. 2 which contains DOC, DPF, DEF and SCR as the main components of the system. Engine exhaust is routed into the DOC, which converts hydrocarbons into carbon particles. The carbon particles are collected and stored by DPF. These soot particles are burned on a regular basis. SCR is used to reduce NOx emissions in the fume gas by using alkali (NH$_3$) as a reductant (Biswas et al. 2009).

The exhaust of a diesel engine contains about 17% unused oxygen by volume which is used for the oxidation of hydrocarbons. Hydrocarbons and carbon mono oxides are converted to carbon dioxide and water by DOC. DOC is usually installed before DPF to use nitrate oxidation to regenerate the particles (Kurien & Srivastava 2018). It's been discovered that oxidation releases a lot of heat, which raises the temperature of the exhaust line that supports the DPF. The temperature of the exhaust gas is projected to increase by 90°C for every 1% oxidation of CO (Reşitoğlu et al. 2015).

The use of DOC in the upstream affects the CDPF's efficiency. DOCs have been a major invention for diesel motors since their introduction in the 1970s (Wang & Baek 2008). With the use of DOC, the proportion of NO2 is increased, and a faster rate of particle emission is seen, decreasing the lower side temperature. By oxidizing a portion of the hydrocarbons that are adsorbed onto the carbon particles, DOCs help to reduce the bulk of diesel particulate emissions (Wang et al. 2012). Using the combination of DOC and DPF can reduce 90% of particles, 80% hydrocarbons, and 45% of carbon mono oxide (CO) (Zhang et al. 2018). In the untreated motor that fumes gas, the NO$_2$ part in the NOx is just around 10 % at most working focuses. The capacity of the DOC increases the rate of NO$_2$:NO by inducing thermodynamic concord (Lee et al. 2013, Sampara et al. 2007). Because of the negative effects of NH3 and to avoid consumption of NH$_3$ before the response, NH$_3$ is produced from a fluid arrangement of urea (Hamada & Haneda 2012). DEF is an aqueous solution with 32.5% urea and 67.5% deionized water which is sprayed in the exhaust stream for the reduction of NOx. The consumption of DEF was found to be 2% of fuel consumption. Spray wall impingement of UWS was investigated in a constant volume chamber by numerical

simulation using STAR CCM+ CFD code. The investigation reveals that wall temperature is the most important parameter that significantly affects spray development after impingement, droplet size distribution, wall film formation, and droplet evaporation. Increasing the wall temperature leads to longer spray front projection length, smaller droplet size, faster droplet evaporation and smaller film thickness, which are preconditions for urea crystallization reduction. The numerical model and parameters were validated by comparing with experimental data (Shahariar et al. 2018)
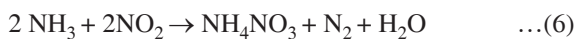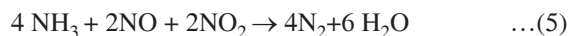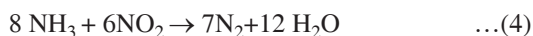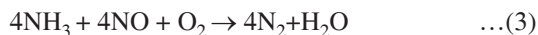
When DEF is injected into the exhaust stream, urea decomposes into ammonia and isocyanic acid due to exhaust temperature.

$$(NH_2)CO(NH_2) \text{ (molten)} \rightarrow NH_3 + HNCO \qquad …(1)$$
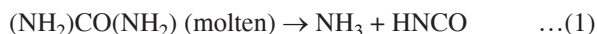
Due to the hydrolysis of this isocyanic acid, ammonia and carbon dioxide gases are produced.

$$HNCO + H_2O \rightarrow CO_2 + NH_3 \qquad …(2)$$
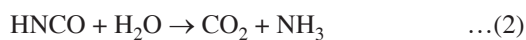
Now ammonia in the presence of oxygen and a catalyst present in SCR reduces the oxides of nitrogen

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + H_2O \qquad …(3)$$

$$8 NH_3 + 6NO_2 \rightarrow 7N_2 + 12 H_2O \qquad …(4)$$

$$4 NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6 H_2O \qquad …(5)$$

$$2 NH_3 + 2NO_2 \rightarrow NH_4NO_3 + N_2 + H_2O \qquad …(6)$$

Equation (1) shows how urea in molten form is decomposed into ammonia and hydrocyanic acid when it comes in contact with the high temperature of the exhaust. Equation (2) represents the hydrolysis of isocyanic acid in which ammonia and carbon dioxide are the main product. These two reactions occur without the requirement of any catalyst. Equation (3) can be considered as the standard reaction where the same amount of ammonia and NO react with oxygen. Equation (4) represents the slow and fast SCR reactions. Some undesirable reactions also take place as a result of which ammonium nitrate is produced at low temperatures below 200°C. These undesirable reactions reduce the conversion of NOx and result in urea slip (Kurien et al. 2018). The efficiency of conversion of NOx is one of the major parameters in the performance analysis of SCR

NOx conversion = [1 – (NOx out/NOx in)] × 100%

(Peng et al. 2015)

## Catalysts used in SCR

Copper zeolite and iron zeolite are widely used catalysts in SCR. The reason being their high-temperature stability and good performance when working at low temperatures. Copper zeolite-based SCR was found to be comparatively better than Fe zeolite due to their higher ammonia storage capacity and oxidation which results in reduced ammonia slip (Guan et al. 2014).

In addition to copper and iron zeolite, Vanadium based SCR catalysts, $SiO_2$ and $TiO_2$ are also used as catalysts. Monolith catalysts are also used. Manganese-based catalysts show good performance characteristics while using low-temperature SCR systems as efficiency is not much affected (Gao et al. 2017).

## Challenges in SCR

Various urea SCR systems have been used in trucks and passenger cars (Lacin et al. 2011). The solution of Urea is injected into the catalytic tank of SCR with help the of a nozzle but it shows a low ammonia carrying capacity (Qu et al. 2014). The major problem in SCR is the freezing of DEF at temperatures below -11°C which necessitates an integrated electric heater in the tank of DEF. Diesel particulate filter (DPF), consisting of alternately plugged parallel square channels with porous walls that trap the soot particles, must be periodically regenerated. In this work, a new procedure for the preparation of microwave susceptible catalytic DPFs based on a preliminary controlled chemical erosion of the porous structure was optimized, so obtaining catalytic filters with higher catalyst load (30 %wt $CuFe_2O_4$). The filters showed pressure drop values very similar to those pertaining to the uncatalyzed filters and a higher regeneration activity: consequently, their microwave-assisted regeneration phase, compared to the traditional fuel postinjection, allowed an energy saving of about 60 % (Kurien et al. 2018). With SCR systems the cylinder of DEF needs to be filled frequently usually before the fuel tank gets empty.

Urea-water spray impingement is an important parameter that affects solid deposit formation, should be investigated duly. A study presented an experimental investigation of urea-water spray impingement on the heated wall of automotive SCR systems for diesel engine exhaust gases. The investigation focused on the impingement conditions and distribution of the spray droplets, which are important parameters for system performance. The investigation reveals that high wall temperature produces swirls and bouncing that entrain rebounded droplets of the impinging spray on the wall, which leads to improved mixing. High temperature also causes longer spray front projection length which is an important factor for the mitigation of urea deposits (Hasan et al. 2019)

## Solid SCR

The SSCR technology uses a powerful reducing agent with a higher ammonia density. With the help of a nozzle, ammonia is directly injected into the downstream side in this method.

Issues such as urea nozzle blockage, low catalyst productivity, and low NOx effectiveness are eliminated due to the shorter mixing time and lower decomposition temperature of ammonia salt (Zhang et al. 2014). A solid reductant-based SCR system is observed to be an effective alternative for ammonia generation as compared to urea-based SCR systems. Ammonium salts like ammonium carbamate and ammonium carbonate have the ability to generate ammonia for about 80-90% NOx conversion for small-, light- and, medium-duty diesel engine applications. Undesired reactions occurring in urea-based SCR systems during cold start and cold transient cycles can be rectified by the introduction of SSCR systems which will also reduce the deposit risks. The performance of the SCR system can be enhanced by using solid reductants for ammonia generation owing to its higher ammonia generation density hence the refill interval can be extended (Kurien & Srivastava 2019). Solid SCR has a lower capacity requirement (up to 28%) than aqueous urea-based SCR, which is an attractive aspect. The usage of Ammonium carbamate also eliminates the freezing problem with aqueous urea. Another advantage of SSCR versus SCR is that ammonia mixes better with exhaust gases. (Krüger et al. 2003). SCRs that use solid ammonia salts for ammonia generation improve NOx reduction efficiency while also increasing the energy needed to heat the salt (Kim et al. 2014).

Solid SCR uses a set up involving DOC, Diesel particulate filter (DPF) that maintains the pressure drop. DOC reduces various oxides except for the oxides of nitrogen.

Diesel particulate filter (DPF) uses a ceramic made substrate in form of a honeycomb structure. DPF captures and stores the exhaust carbon particles. Because the exhaust temperature is so high, the carbon particles in this filter are burned and quickly released into the environment. The most typical work is to reduce the oxides of nitrogen. For this purpose, a solid catalyst is used in SSCR systems.

Fig. 3 shows a composite type of SSCR system in which two systems are used for producing heat to decompose the solid salt. When the engine starts, the temperature of water in the water tank remains insufficient to produce heat for the decomposition of solid salt. At this time electronic unit produces the heat, thus providing ammonia gas. When the engine is in running condition and is warmed up, the electronic unit stops working automatically and the heat of the water tank is used for decomposing the solid salt thus providing ammonia gas. Urea in aqueous form is not able to produce a higher amount of ammonia. In SCR systems using DEF produces Cyanuric acid and some other acids which gives rise to blockage of urea nozzle, decreases the catalyst activities thus reducing the NOx efficiency (Zhang et al. 2014).

Injection of urea at a specific temperature is required in these systems. The above-mentioned problems can be reduced from SCR systems if ammonia is directly injected into the exhaust. This is the basic concept of SSCR where ammonia is generated with the help of a solid reductant. In SSCR systems the mass of reductant is reduced, the reason
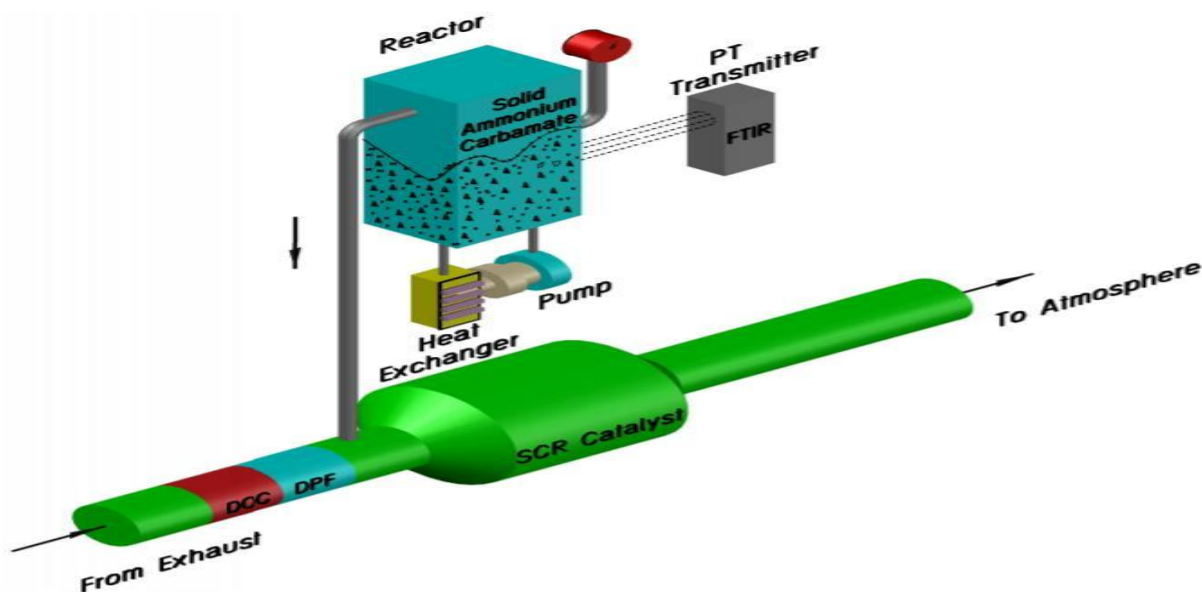


Fig. 3: Solid SSCR system.

being the higher ammonia densities of solid salts. Emission reduction is also increased at lower temperatures which eliminates the problem of deposition risks. Compared to the SCR system, in SSCR decomposition occurs at lower temperatures and also reduces the mixing time. Generally used ammonia salts for the production of ammonia gas are ammonium carbamate, ammonium carbonate, amino strontium chloride, amino calcium chloride, etc. (Zhang et al. 2014). Among various available salts, ammonium carbamate is found to be the best option to use in the SSCR system in India as it has a minimum decomposing temperature. Ammonium carbamate decomposes fully at about $60^{\circ}C$ (Zhang et al. 2014). Metal salts of amino having decomposed temperatures of $30^{\circ}C$ to $50^{\circ}C$ are not opted in India due to their preservation complexities.

Ammonia slip is considerably reduced with the use of CDPF after SCR using slip catalyst. a study concluded that CDPF's reduce ammonia to $N_2O$ and NOx but the overall conversion efficiency of the NOx is increased (Girard et al. 2007). The schematic diagram of the diesel after-treatment system using ammonia slip catalyst is shown in Fig. 4

Kim et al. (2014) investigated the possibility of a new ammonia generation system that uses low-cost solid ammonium salt, such as solid urea and ammonium carbonate. The result showed that ammonium carbonate is more suitable than solid urea because of the low decomposition temperature and no change to the other ammonium salt during the decomposition process. This paper also showed the NOx reduction capability of the new ammonia delivery system that uses ammonium carbonate for the comparison of NOx reduction using solid urea and ammonium carbonate as salts for producing the reducing agent ammonia.

It was discovered that solid urea requires a high decomposition temperature and that during this process, unwanted chemicals such as cyanuric acid are formed. The ammonium carbonate system was found to be significantly more suitable because of its low breakdown temperature. However, due to the removal of water produced during the process, more attention must be taken when constructing the system. The effect of numerous parameters on the decomposition reaction, such as temperature, pressure, and salt mass, was not taken into account in the experiment (Kim et al. 2014)
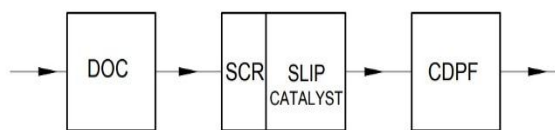


Fig. 4: Diesel after-treatment system using ammonia slip catalyst (Girard et al. 2007).

In 2011 a system containing ammonium carbamate for the production of ammonia was developed by Lacin et al. (2011). This system could not explain the effect of various parameters which affect the thermal decomposition of ammonium carbamate (Lacin et al. 2011).
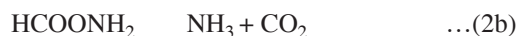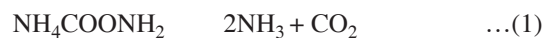
In 2013 an experiment using thermogravimetric analysis and a calorimeter was conducted by Lee et al. (2013) for calculating the energy required for thermal decomposition of ammonium salts. Sufficient data was provided to understand the chemical reaction but they failed to develop any mathematical model for the production of ammonia using ammonia salts (Lee et al. 2013)

Kim et al. (2020) experimentally provided the information regarding optimum production of ammonia for reduction of NOx using ammonium carbamate as the salt for the production of reducing agents. They also investigated the effect of temperature, pressure, and mass of ammonium carbamate on the decomposition rate of the salt (Kim et al. 2020)

The rate of decomposition of ammonium carbamate varies linearly with temperature. At high temperature, the rate of thermal decomposition is high thus requiring a robust reactor design which can bear high pressure. The size of the reactor must be large enough to reduce the frequency of refilling the reactor with ammonium carbamate. The mass of salt present in the reactor influences the reaction rate of decomposition. The optimized reaction rate of decomposition of salt is obtained only when the mass of salt present in the reactor is high. The reactor should be refilled as soon as the pressure in the reactor is observed less than injection pressure (Kim et al. 2020)

## Chemical Kinetics of Decomposition

Ammonium carbamate thermally decomposes into alkali and carbon dioxide. Ramachandran et al. (1998) researched that decomposition of ammonium carbamate happens in two phases hence delivering moderate items.

$$NH_4COONH_2 \qquad 2NH_3 + CO_2 \qquad \qquad …(1)$$

$$NH_4COONH_2 \qquad NH_3 + HCOONH_2 \qquad …(2a)$$

$$HCOONH_2 \qquad NH_3 + CO_2 \qquad \qquad …(2b)$$

Equation (1) was given by Kim et al. (2014) and shows that solid ammonium carbamate can remain in equilibrium with the products obtained after decomposition. Equations (2a) and (2b) were predicted by Ramachandran et al. (1998) which explains that the decomposition of ammonium carbamate occurs in two stages.

The thermal decomposition of ammonium carbamate is also influenced by the mass of ammonium carbamate inside the reactor. When the ammonium carbamate mass is low,

an acceptable decomposition rate is impossible to achieve. In this case, it's critical to set a high temperature to ensure a sufficient decomposition even when the ammonium carbamate mass is minimal (Kim et al. 2020).

## CONCLUSION

The development of a reliable NOx reduction method using SCR and SSCR is investigated in this paper. SSCR technology has been found to be a considerably better solution for reducing NOx emission from diesel engine exhaust. The use of ammonia as a reducing agent improves NOx emission reduction and so complies with the BS-VI standards. When vaporized ammonia is used as a reducing agent, ammonia slip and lower reduction efficiency are decreased to a greater extent. As a result, due to its large ammonia storing capacity and lower decomposition temperature, ammonium carbamate is shown to be the best option. Because SSCR technology can function effectively at temperatures as high as 200°C, it is useful in diesel engines. The use of ammonia as a reducing agent allows the technology to operate at temperatures below 200°C, resulting in more efficiency in NOx conversion and hence greater control over decomposing. The findings reveal that a successful SSCR framework can lead to a smaller reductant tank and, as a result, lower filling frequencies. This study concludes that SSCR is a superior method for reducing NOx emissions from diesel engines' exhaust. The use of ammonia gas instead of urea greatly reduces pollution and malfunctioning issues. The use of SSCR allows for efficient operation even at low temperatures, and the problem of DEF freezing at low temperatures is eliminated. This research lays the groundwork for minimizing ammonia slip in SSCR systems to achieve a highly efficient NOx emission reduction system.

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