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# Particulate Matter and NOx Exhaust After Treatment Systems

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***Abstract:** It is today undoubted that humans have to reduce their impact on the environment. Internal combustion engines, being the major power source in the transportation sector as well as in individual transport, play an important role in the man-made emissions. While the mobility in the world is growing, it is important to reduce the emissions that result from transportation. The diesel engine provides a high efficiency and hence it can help to reduce CO2 emissions, which are believed to be the main cause of global warming. Diesel exhaust also contains toxic gases, mainly nitrogen oxides (NOX) and soot particles. These emissions are therefore limited by the authorities in most countries. A way to reduce the nitrogen oxide emissions of a diesel engine is the use of exhaust gas recirculation, EGR. Here, a part of the exhaust gases is rerouted into the combustion chamber. This leads to a lower peak combustion temperature which in turn reduces the formation of NOX. In modern turbocharged engines it can be problematic to provide the amount of EGR that is needed to reach the emission limits. Other concerns can be the transient response of both the EGR-system and the engine. This work provides a simulative comparison of different EGRsystems, such as long-route EGR, short-route EGR, hybrid EGR, a system with a reed valve and a system with an EGRpump. Both the steady-state performance and transient performance are compared. In steady-state the focus is the fuel efficiency. In transient conditions both the reaction on changed EGR-demands and the torque response are analyzed. Fleet fuel consumption is greatly reduced through the introduction of the HSDI Diesel engine. The reduced fuel consumption is then reflected in a reduction of CO2 emissions. The drop in fuel consumption and CO2 emissions results in a rise in market acceptance, which is also the result of desirable driving performance and greatly improved NVH behavior. The continuously increasing demands on placed on emissions performance also needs to be addressed. Particulate emissions can be reduced by more than 95% through the use of a diesel particulate trap. However, based on current knowledge, a further, substantial NOx engine out emission reduction for the diesel engine counteracts one of the other goals, which is reduced fuel consumption. Diesel engine compliance with current and future emission standards will require DeNOx technologies. Currently, the NH3-SCR and Lean NOx-Trap (LNT) technologies show the most promise as solutions to achieve the strict NOx standards. While the NH3-SCR technology addresses fuel consumption, the application of an additional reduction component is considered a drawback. Combining DeNOx technologies with the application DOC/DPF requires a detailed and thorough analysis of exhaust system layout at the very beginning of the engine development cycle. Modeling and simulation of emission and fuel consumption are required to determine the appropriate level of technology needed for various applications.***

***Keywords:** Bharat Stage VI, Sustainable Mobility, Engine Downsizing, Onboard Diagnostics.*

## I. INTRODUCTION

In the “State of Global Air” report published earlier this year, exposure to ambient particulate matter < 2.5 microns (PM2.5) was identified as the 5th largest risk factor to health, accounting for 4.2 million deaths across the globe. The report highlights measurements which show that 92% of the world’s population lives in areas that exceeded the 10 µg/m3 guideline recommendation by the World Health Organization (WHO). The poor air quality is also associated with some of the most densely populated and rapidly growing economies of the world. Accordingly, measures are being taken across several developing countries to adopt and enforce tighter vehicular emission regulations to minimize tailpipe unburned hydrocarbons, NOx and particulates. The societal needs for lower greenhouse gas (GHG) emissions have also increased focus on improvements in vehicle fuel economy and powertrain electrification. This has led to the adoption of fuel efficiency and/or tailpipe CO2 targets by several countries. Moreover, the emphasis on reduced emissions has shifted worldwide from lab-based certification cycles to real-world driving conditions. Much thought has been put into developing testing procedures to measure real-driving emissions (RDE). This triple confluence of reduced tailpipe emissions of criteria pollutants, improving fuel economy and achieving these under a wide range of real-world driving conditions is a significant challenge facing the automotive industry. This paper describes recent advances in both the regulations across the world as well as engine and after-treatment technologies.

Diesel engine applications have achieved approximately a 50% market share in Europe and are beginning to gain a share of the U.S. market as well. The increased market share is due to its superior fuel economy, excellent driving performance, good acoustics as well as lower exhaust emissions. Advanced technologies such as common-rail, turbocharging, cooled EGR as well as sophisticated control algorithms have helped to increase the overall performance of the modern diesel engine. The particulate filter is becoming a state-of-the- art technology for diesel engines, to promote its image as a clean engine.

However, significant advancements in engine-out emissions as well as exhaust aftertreatment technologies will be required for these engines to achieve the upcoming strict emission standards such as EU6 or U.S. Tier2. Also, the state-of-the-art Diesel Oxidation Catalyst (DOC), the Diesel Particulate Filter (DPF) as well as highly efficient Nox aftertreatment technologies will become mandatory in the future. Reducing emissions of the nitrogen oxide (NOx) in diesel engines will become one of the greatest developmental challenges for the future. The primary goal of the future is to maintain the diesel engine as a propulsion source with highest fuel economy. Currently, only the lean NOx trap (LNT) and SCR technology present promising capabilities to achieve the required NOx reduction targets. Recently, SCR technology has been marketed for HD applications in Europe and Japan. It is also slated for market introduction for passenger cars and light-duty trucks in Europe as well as U.S. Europe and Japan have seen the introduction of LNT technology for lean-burn gasoline engines as well as for diesel engines as with the integrated DPNR technology approach made by Toyota. In addition to pure LNT and SCR system concepts, combinations of LNT and SCR technology are currently being published, such as by DaimlerChrysler for the E320 Tier 2 Bin 8 BLUETEC concept or Honda with regard to their Tier 2 Bin 5 aftertreatment concept. Due to the increased interest in the marketplace, the highspeed DI (HSDI) Diesel engine contributes substantially to the decrease of fleet fuel consumption thus in the reduction of CO2. Typically, internal measures taken to decrease exhaust emissions – especially NOx emissions – inherit the drawback of increasing fuel consumption without compensation measures and therefore offset the realization of targets for CO2 emissions.

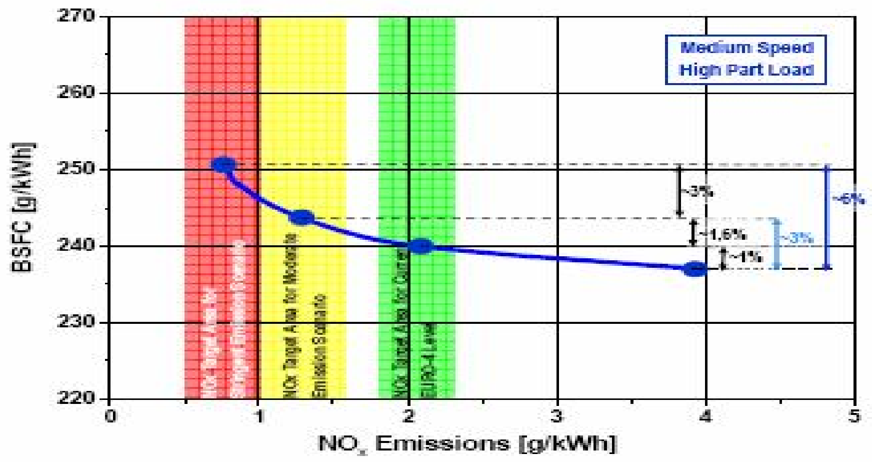


Figure 1 Impact of Conventional Internal NOx Reduction Measures on BSFC

*A. Objective*

This invention relates generally to an exhaust gas after treatment System for internal combustion engines and more particularly to a NO aftertreatment System for lean burn engines.

## II. LITERATURE REVIEW

### *A. Emission Legislation*

The concern for the environment is reflected in emission regulations that are established in most countries in the industrialized part of the world. New production cars have to pass certain emission limits in order to get approved for sale. The test differs for different regions and also for different types of vehicles. Figure 2 shows the speed profile of the modified new European driving cycle (MNEDC), which is the test procedure for passenger cars in Europe [8]. During the test, the car is run on a chassis dynamometer, following the speed profile, while the tailpipe emissions are measured. For diesel engines the critical emissions are typically those of NOX and PM. The limits for these emissions have been decreasing a lot in recent years, as can be seen in Figure 3.

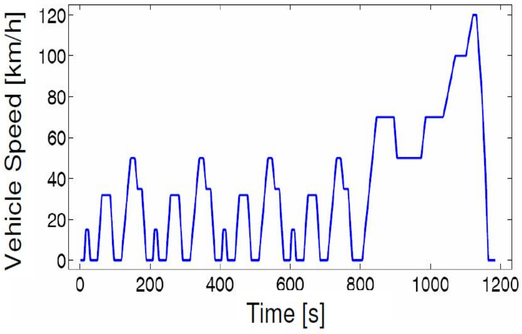


Figure 2 Speed profile of the MNEDC.

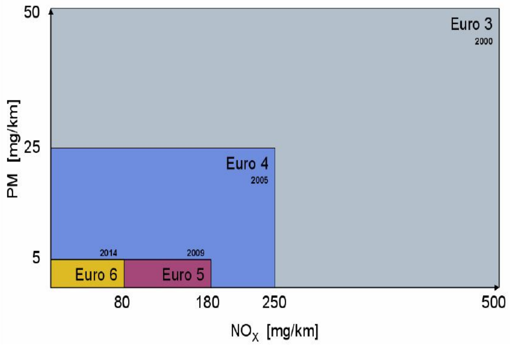


Figure 3 Development of Soot and NOX emission limits.

### *B. Nitrogen Oxides (NOx)*

Nitrogen oxides, NO and NO2, are referred to as NOX. They are harmful for the lungs when local concentrations get too high. They also contribute to acid rain and form smog in combination with hydrocarbons.

NOX formation takes place in combustion zones with high oxygen concentration and high combustion temperatures. The most important mechanism for NOX formation in internal combustion engines are thermal NOX and prompt NOX. A theoretical approach to the thermal NO formation is the extended Zeldovich mechanism. It consists of three chemical reactions that form NO:

$$O^{*} + N_2 \leftrightarrow NO + N^{*}$$

$$N^{*} + O_2 \leftrightarrow NO + O^{*}$$

$$N^{*} + OH \leftrightarrow NO + H^{*}$$

The triple-bond in the N2 molecules makes a high energy necessary to activate these reactions. Therefore, they are only fast enough to form significant amounts of NOX if the temperatures are above 2200 K .

### *C. Particulate Matter (PM)*

Particulate matter, often referred to as soot, is the other problematic emission from diesel engines. They are suspected to be carcinogenic. In addition to that, they have been shown to increase respiratory symptoms and increase mortality in cardiovascular and respiratory diseases.

Soot formation is not entirely understood. A widely accepted explanation divides it into several steps. It starts with the formation of molecular precursors of soot, polycyclic aromatic hydrocarbons (PAH). These PAHs build up from benzene under addition of C2, C3 or other small units to PAH radicals. During the next steps, the nucleation of particles, the PAHs collide with each other and stick together to build clusters and evolve into solid particles.

The mass of these particles is then increased via the addition of gas phase species such as PAH and acetylene. Coagulation occurs via particle-particle collisions which decreases the particle number while the particle size grows. The coagulation takes place shortly after the formation of particles while the agglomeration occurs in later stages of soot formation. Here, three-dimensional structures can form of particles that stick together.

## III.NOX AFTERTREATMENT TECHNOLOGIES

From today’s point of view, only lean NOx trap (LNT) and SCR technology represent promising solutions to achieve future NOx reduction targets. One possibility to reduce tailpipe emissions of a vehicle is the use of aftertreatment system in the exhaust path. The most common ones are described here. The operating principle as well as the specific pros and cons of the two different technologies will be described in more detail.

### *A. Lean NOx Trap (LNT) Technology*

The lean NOx trap (LNT) or NOx absorber catalyst (NAC) is a discontinuously operating aftertreatment technology and is characterized by the following operating modes:

- NOx storage during lean engine operation
- NOx reduction during rich operation phases
- LNT desulfurization under rich conditions and high temperatures

The most challenging operating modes of a LNT under real transient conditions are the rich operation of the Diesel engine, the transitions between lean and rich operation, the desulfurization process as well as control of the LNT system including sensors.

Due to its operating principle the mixture-controlled (quality-controlled) Diesel engine operates with a high amount of excess oxygen, particularly under part-load, which is most relevant especially for light-duty applications. A thorough optimization of the Diesel engine air and fuel management is required in order to reduce the high amount of excess oxygen in the rich operating condition. The removal of oxygen is essential for a successful regeneration of the NOx absorber catalyst. Therefore efficient calibration methodologies based on DoE (Design of Experiments) approaches, which consider aspects like oil dilution, component limits, CO/HC-ratio, black smoke emissions, combustion noise, sensor requirements as well as the requirement for smooth maps and map transitions during the calibration process are necessary.

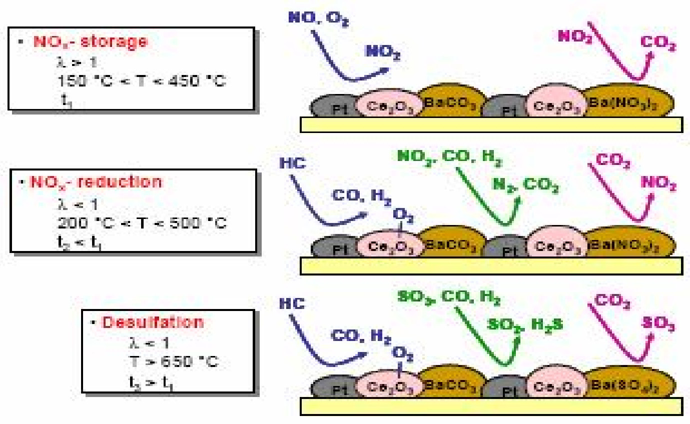


Figure 4 LNT Operating Modes.

Furthermore sophisticated and robust control functionalities for the transition between lean and rich engine operation have to be developed and implemented. Besides the definition of a suitable control strategy, an appropriate sensor setup represents an important task. This includes detailed assessment of the sensor signal quality with regard to the demands for LNT system control in order to enable a control strategy targeting for high NOx-conversion efficiencies with lowest fuel consumption penalty and also enabling the detection of thermal aging as well as sulfur poisoning of the LNT.

Efficient desulfurization of current state-of-the-art LNT technologies require high temperatures of at least 650°C in combination with locally rich exhaust gas conditions within the catalyst. To avoid severe thermal aging of the LNT, sophisticated temperature control strategies have to be developed. The major portion of Sulphur will be released as H2S from the LNT during an efficient desulfurization event. Because significant amounts of H2S cannot be emitted into the atmosphere, a post-oxidation of the H2S has to be ensured. This can be achieved by a suitable management of oxygen downstream of the LNT; e.g. using a control strategy based on the oxygen storage capacity of any catalyst placed downstream LNT in the exhaust line.

The main challenges of LNT technology can be summarized as follows:

- DeNOx regeneration by engine internal measures in terms of drivability and driver transparency
- Limited DeNOx regeneration operation area
- Sulphur poisoning / desulfurization
- Reliable desulfurization strategy
- Long-term stability / thermal aging
- DeNOx and DeSOx management / complexity of aftertreatment control

### *B. Selective Catalytic Reduction (SCR) Technology*

Selective catalytic reduction stands for a NOX reduction technology. A catalyst converts the NOX emissions with the help of a selective reducing agent. Ammonia, NH3, is the most common one for this purpose. As ammonia is toxic, it is formed from an ammonia carrier inside the exhaust system.

Urea is widely spread because of its solubility in water. A urea/water solution is metered into the exhaust system and converted into NH3 and CO2. NH3 is then used for the reduction of the NOX. In modern systems, both these steps are performed in one catalyst. Urea/water solution is marketed under different names, e.g. AdBlue or Diesel Exhaust Fluid. Figure 5 shows the build-up of such a system.

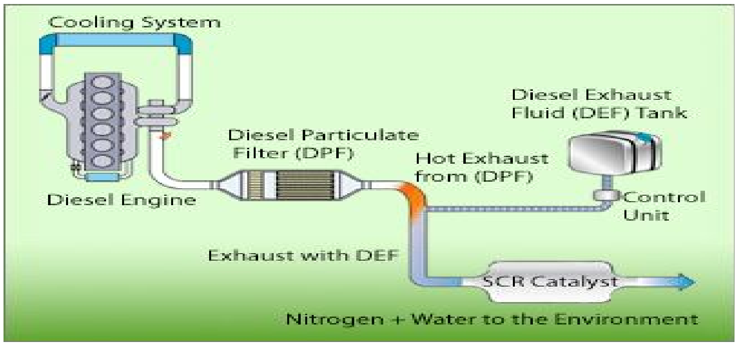


Figure 5 SCR System Schematic.

An advantage of such a system is the possibility to focus on the engines fuel consumption in the calibration, as the aftertreatment takes care of the emissions. Disadvantages are the extra hardware and the extra operating fluid that have to be built, transported and refilled. According to Cloudt et al. the SCR-system can show to be the more fuel efficient solution for Euro 6 applications than the use of EGR.

SCR technology is based on reduction of NOx by ammonia, which has to be generated on-board from a suitable reductant, since a transportation of pure ammonia is not desired or advisable. Today the usage of urea/water solution (“Adblue”) is most common for SCR systems. Aside of the liquid urea also alternative system concepts based on ammonia carbamate or solid urea are under development.

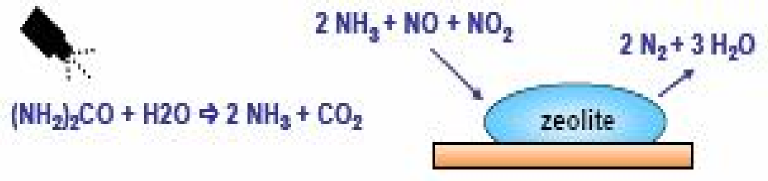


Figure 6 SCR Operating Modes.

For passenger car and light-duty applications current concepts are utilizing non-air assist urea injection systems and zeolite type catalysts. For the urea dosing, a reliable operation of the injector and a uniform distribution of urea in the exhaust gas stream has to be achieved under all relevant operating conditions. Furthermore the dependency of low temperature activity on NO2 content in the exhaust as well as the formation of exhaust components such as N2O, NH3, formic acid or iso-cyanuric acid has to be examined carefully. SCR catalysts are characterized by complex processes of ammonia storage, NOx conversion as well as ammonia slip and therefore detailed characterization of the SCR catalyst as well as sophisticated control algorithms are required in order to achieve high NOx conversion rates while maintaining low ammonia slip under transient operating conditions.

The main challenges of SCR technology can be summarized as follows:

- Reliable urea injection
- Uniform ammonia distribution in the exhaust
- NOx neutral SCR-catalyst heating-up strategy
- Dosing strategy
- Ammonia slip
- Vehicle package
- System costs

### *C. Diesel Oxidation Catalyst (DOC)*

An oxidation catalyst oxidizes the unburned or only partly burned species in the exhaust gas, namely HC and CO, by using the oxygen from excess air. It consists of a catalytic material, mostly platinum, which is fixed on a porous substrate. The substrate forms a large number of channels through which the exhaust gas passes, in order to form a large reaction surface. Other functions of the DOC can be the conversion of NO into NO2 to help other aftertreatment devices, or the use as a catalytic burner. This would increase the exhaust gas temperature e.g. for particulate filter regeneration.

### *D. Diesel Particulate Filter (DPF)*

In a diesel particulate filter the soot particles in the exhaust gas are filtered out. The filter is built up similarly to the oxidation catalyst, with a ceramic substrate building small channels. But here, every other channel is plugged on the intake or outlet side respectively. This means that the exhaust gas has to pass through the porous substrate. Most of the soot particles do not pass through the material but accumulate in it.

This leads to a growing load of soot in the filter which increases the pressure drop over the filter. After some time, the filter has to be regenerated to restore the original pressure drop. To regenerate the filter, the stored soot mass, which mainly consist of carbon, is burned off. As the temperatures that are needed for this are seldom reached in normal driving conditions, the regeneration has to be activated in another way. There are two ways of regenerating, passive and active regeneration. For passive regeneration some fuel additive or a catalytic coating on the DPF is used to reduce the temperature at which the soot can be burned to around 450 °C. Active regeneration means that the exhaust gas temperature is increased so that the soot burns naturally, at around 600 °C. This can be achieved by late injection of fuel into the combustion chamber, which then is burned in the oxidation catalyst.

### *E. Comparison of LNT and SCR Technology*

In order to achieve lowest NOx tailpipe emissions over the desired emission certification test cycles, the NOx conversion efficiency as a function of exhaust temperature is one of the most determining factors. Nevertheless, the specific boundary conditions and limitations of either LNT as well as SCR technology have to be considered in order to allow a fair comparison of the two aftertreatment technologies.

Systems configurations with a DeNOx system placed upstream of a CDPF, which are expected to be more beneficial with regard to NOx reduction performance under lower engine-out temperature conditions, will be more common in light-duty vehicle applications. A more detailed assessment of combined NOx aftertreatment and DPF systems will be performed in the following section Figure 7 shows typical idealized NOx conversion efficiency curves for LNT and SCR systems. For both technologies a more ´low temperature´ oriented coating technology as well as a more ´high temperature´ oriented coating technology are depicted.

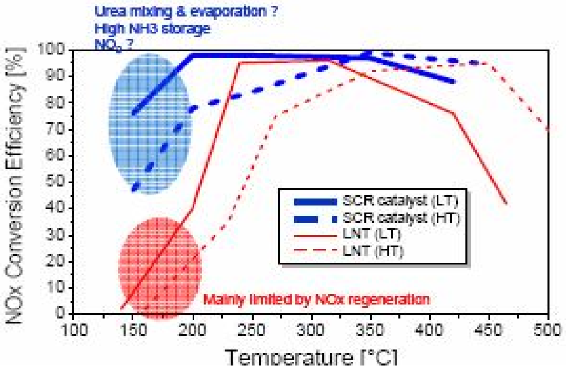


Figure 7 General Comparison of LNT and SCR Technology.

Considering the temperature dependency of the NOx conversion efficiencies, there is a clear advantage of the SCR technology, as SCR can achieve highest efficiencies at low temperature as well as high temperature areas. However with regard to low temperature activity some important differences between SCR and LNT technology have to be pointed out: High NOx conversion efficiencies can only be achieved using the SCR technology with NO2 ratios of about 50% in the exhaust as well as significant ammonia storage on the SCR catalyst. This requires a sophisticated control strategy to avoid ammonia slip. Besides that, the evaporation and mixing of the liquid urea/water solution has to be guaranteed under such low exhaust temperature conditions.

In contrast to that, the LNT technology is mainly limited with regard to NOx regeneration in the low temperature region, whereas LNT catalysts can store significant amounts of NOx even at low temperatures. This first consideration already points out, that a more detailed assessment of the different technologies is required in order to select a suitable technology for a specific application.

Furthermore it has to be taken into account, that an SCR catalyst cannot be positioned really close-coupled to the turbocharger outlet, as there is always a certain length in the exhaust line required for the urea injection and appropriate mixing. In contrast to that the LNT catalyst can be positioned comparably close-coupled to the turbine outlet position if the vehicle package conditions provide the necessary volume. Due to this fact the exhaust temperature at SCR catalyst position will always be less compared to the close-coupled LNT position, especially during the warm-up phase after cold start. In Figure 8 this effect is considered by a temperature decrease of about 60°C between SCR and LNT catalyst position. As a result it becomes obvious, that the close-coupled LNT and the under-floor SCR show nearly the same low temperature performance.

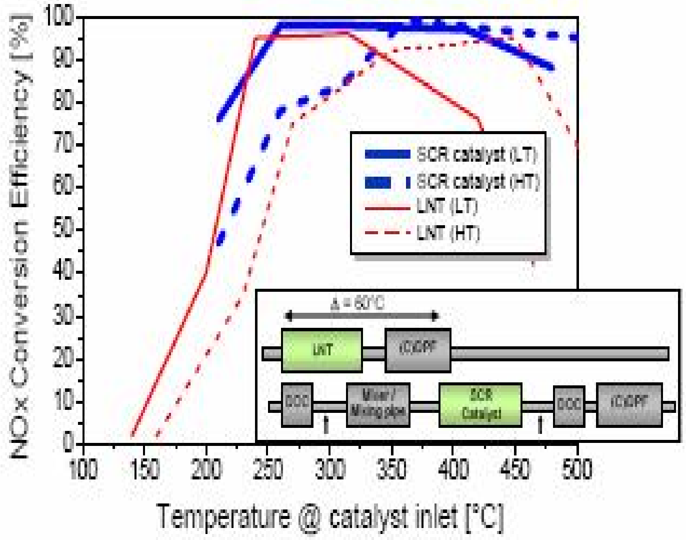


Figure 8 Comparison of LNT and SCR Technology Considering Possible Position in the Exhaust.

The following scenario utilizes a split LNT design which is not possible for the SCR system. As pointed out in Figure 12, such an approach provides the potential to extend the operating window of the LNT concept. In this configuration the close-coupled LNT brick is used to convert the NOx in the low temperature area (e.g. over the FTP75), whereas the under-floor LNT provides the required efficiencies under high temperature operating conditions (e.g. the US06). Further improvements might be achieved with an optimized coating for both bricks.

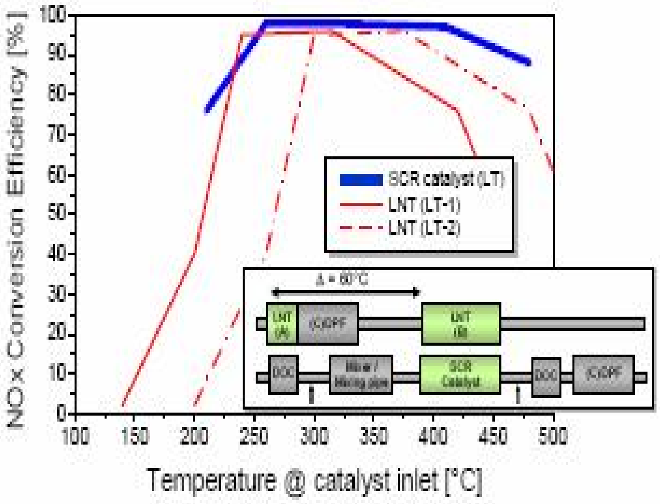


Figure 9 Comparison of LNT and SCR Technology Considering Split of LNT Catalyst into Two Bricks.

## IV. COMBINED PARTICULATE AND NOX AFTERTREATMENT SYSTEMS

For future applications any NOx aftertreatment system will have to be considered in combination with a DPF which can be placed up- or downstream the NOx aftertreatment unit. In contrast to SCR systems, the LNT provides the potential to be placed the in close-coupled location to the engine and/or to split the catalyst into two separate bricks. The different system concepts are depicted in Figure 10.

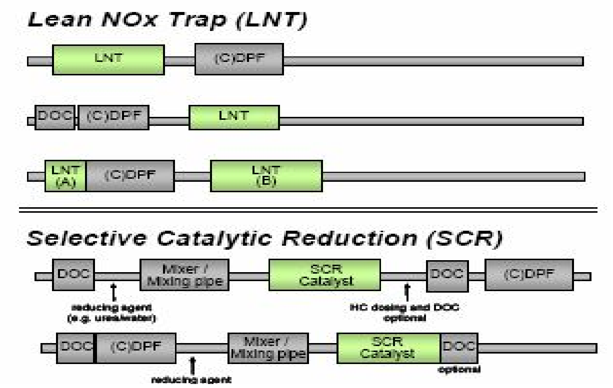


Figure 10 Concepts for Combined DPF and NOx Aftertreatment Systems.

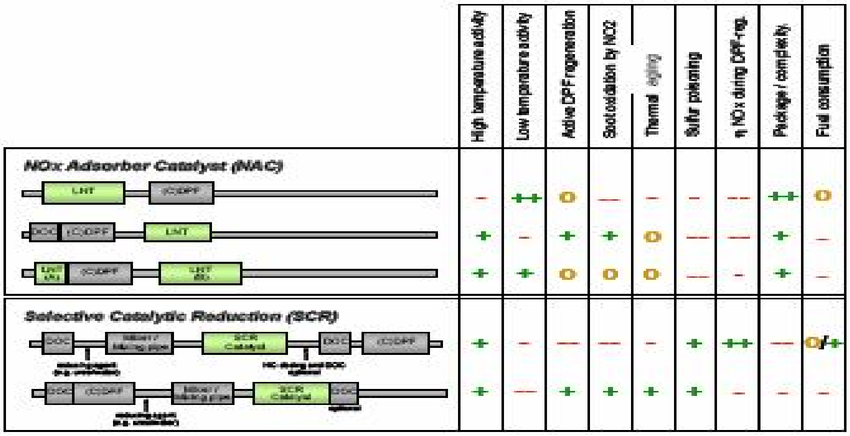
Figure 11 shows an assessment of the different concepts with regard to important factors such as:

- Low / high temperature activity.
- Effort for active DPF regeneration.
- Possibility for soot oxidation by NO2.
- Risk and degree of thermal aging.
- Risk of sulfur poisoning / effort for desulfurization.
- Potential for NOx reduction during DPF regeneration (with regard to emission adjustment factors).
- Packaging demands / system complexity.
- Potential with regard to fuel consumption.

It has to be mentioned, that cost as well as infrastructure related issues are not considered in this assessment.

A comparison and assessment of the different system concepts shows, that there are specific pros and cons for each system. Different approaches result in the optimum choice for each individual application. The LNT technology is favored with regard to packaging conditions and therefore for small vehicle applications. LNT systems have to be considered as bearing significantly higher risk with respect to thermal aging and sulfur poisoning.

In general the LNT provides advantages during low temperature operation, whereas a system layout with SCR downstream CDPF is the only concept enabling significant NOx conversion during DPF regenerations. With regard to DPF related aspects, the LNT has to be considered as more beneficial compared to SCR technology. Thereby SCR is the only technology which even can offer potential for fuel consumption benefits in case of limited NOx reduction demands.



| | High temperature activity | Low temperature activity | Active DPF regeneration | Soot oxidation by NO2 | Thermal aging | Sulfur poisoning | η NOx during DPF-reg. | Package / complexity | Fuel consumption |
|---|---|---|---|---|---|---|---|---|---|
| **NOx Adsorber Catalyst (NAC)** | | | | | | | | | |
| LNT (C)DPF | – | ++ | O | — | – | – | – – | ++ | O |
| DOC (C)DPF LNT | + | – | + | + | O | — | — | + | – |
| LNT (A) (C)DPF LNT (B) | + | + | O | O | O | — | – | + | – |
| **Selective Catalytic Reduction (SCR)** | | | | | | | | | |
| DOC Mixer / Mixing pipe SCR Catalyst DOC (C)DPF | + | – | — | — | – | + | ++ | — | O/+ |
| DOC (C)DPF Mixer / Mixing pipe SCR Catalyst DOC | + | — | + | + | + | + | – | – | – |

Figure 11 Assessment of Concepts for Combined DPF and NOx Aftertreatment Systems.

As a conclusion, any aftertreatment system layout has to be addressed with specific weighting factors for each individual vehicle application.

Once the required NOx conversion rates, the specific boundaries of the legislative test cycles as well as the available space in the vehicle are quantified as decisive factors for the selection of the appropriate NOx aftertreatment technology, the following general trend can be observed: The SCR system is proposed as first choice for large vehicles which require high NOx conversion efficiencies over high vehicle mileage (such as SUVs for US Tier 2 Bin 5 emission standards). The LNT technology is considered as an attractive alternative for smaller vehicles with lower NOx reduction efficiency demand (e.g. for EU5 and post EU5 legislation). Therefore the selection of the aftertreatment technology as well as exhaust system layout is required for each specific application, which has to be supported by simulation of the exhaust system including temperatures in the exhaust system as well as emissions in different driving cycles.

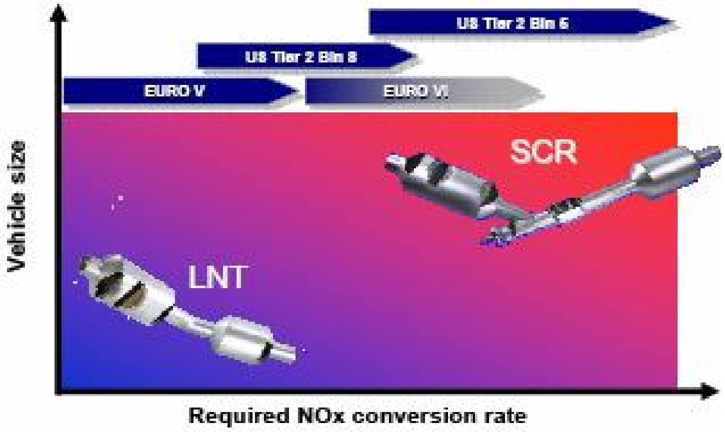


Figure 12 Development Trends for LNT and SCR Technology.

### *A. Simulation Approach*

In the following a tool for fast simulation of temperatures in the exhaust line as well as vehicle tailpipe emissions will be presented and examples for simulation results will be discussed. Such simulations are considered to be essential with regard to selection of a suitable NOx aftertreatment technology for a specific application, e.g. considering factors such as:

1) Vehicle inertia weight
2) Engine-out emission profile
3) Vehicle packaging situation
4) Driving cycle

Simulation of the temperature profile along an exhaust system is critical to calculate the reduction performance of DeNOx systems. The tool used for the calculations within this paper is based on a Simulink model, which provides the possibility for fast and easy abstraction of an exhaust aftertreatment design.

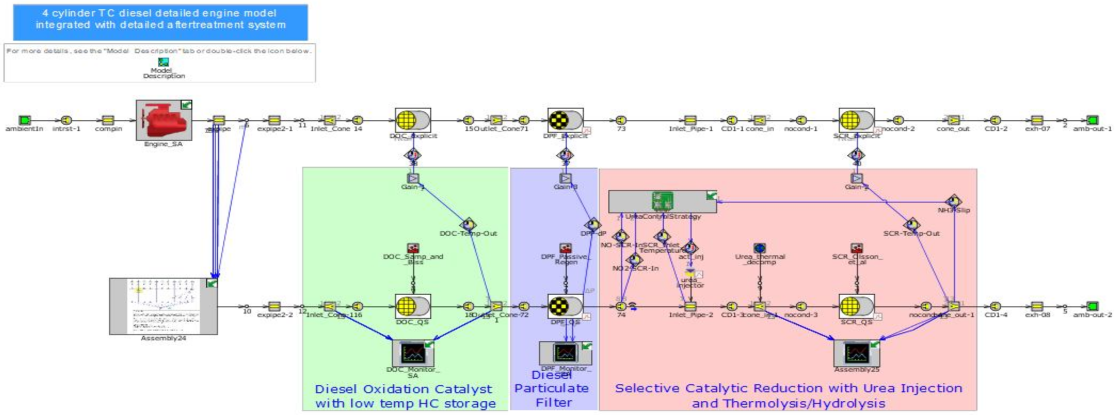


Figure 13 Aftertreatment Simulation - Simulink Temperature Model.

Figure 14 depicts the high level of agreement between measured and simulated temperatures along the exhaust systems especially also at the beginning of the FTP75 driving cycle. Heat releases by chemical reactions as well adsorption and desorption of gaseous compounds on the catalyst surface are implemented by parameterized functions dependent on brick temperature and gaseous matrix.

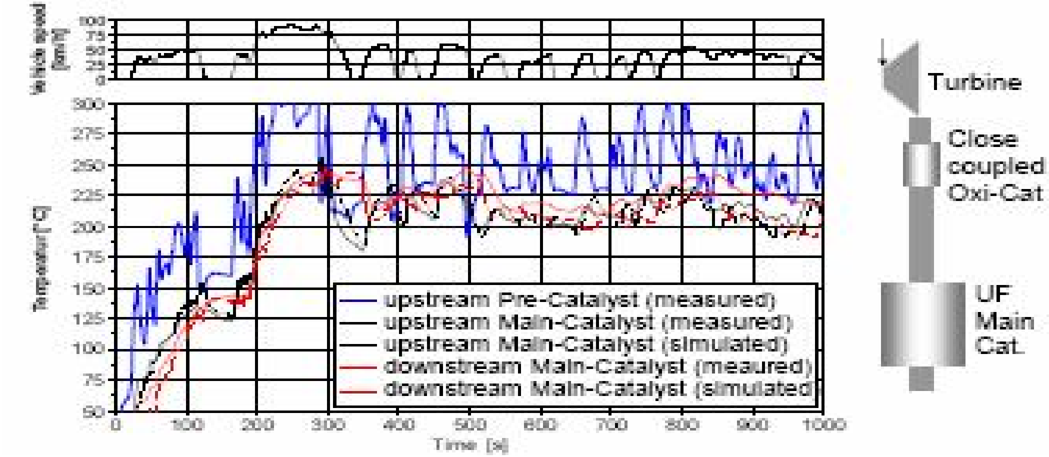


Figure 14 Comparison of Temperature Measurement and Simulation during FTP75-Driving Cycle.

Overall each catalytic brick in the exhaust system can be divided in up to 3 zones with different activity. The basis of the simulation for the DeNOx systems are laboratory experiments on FEV’s own engineered catalyst test bench. Within this test bench catalyst bricks with a maximum length of 8’’ and a diameter of 2” at space velocities between 10,000 and 125,000 1/h can be evaluated with different exhaust gas compositions. It is possible to run validation tests within a temperature range between 25°C and 800°C.

The evaluation results of a typical fresh (de-greened) low temperature LNT are used as an input for the driving cycle simulations, such as NOx storage capacity as a function of temperature, stored NOx and NO2/NOx ratio. The regeneration efficiency for the LNT is simulated as a function of temperature. The management of DeNOx (rich exhaust gas) regeneration is simulated by limitation of maximum fuel consumption penalty (in this case 3.5% are used) and of the maximum amount of stored NOx (in this case 0.3 g are used). The temperature dependent NOx storage capacity of the LNT used for the calculations within this paper is shown in Figure 15.

As an input for the SCR zeolite based catalyst the NH3 storage behavior as a function of temperature and stored NH3 as well the NOx conversion efficiency as a function of temperature and stored NH3 are used in the model simulation. Figure 16 illustrates the maximum NOx conversion efficiencies at SV 50,000 1/h.

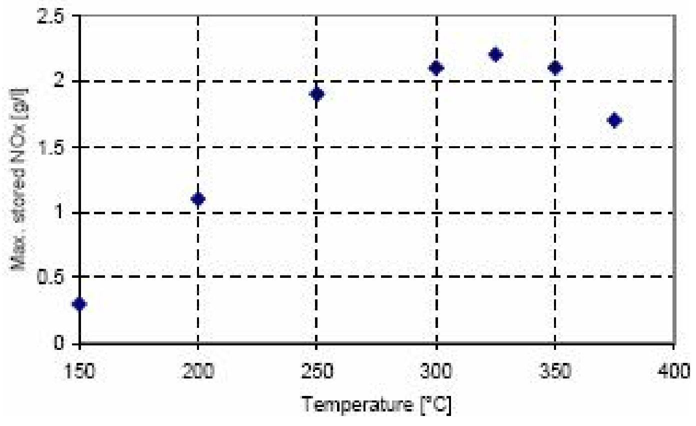


Figure 15 NOx Storage Capacity of the Fresh LNT as a Function of Temperature, SV 50,000 1/h.

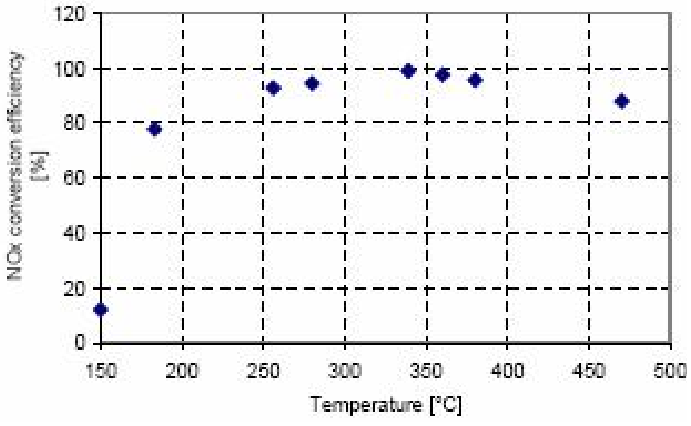


Figure 16 Maximum NOx Conversion Efficiency of the Fresh SCR Catalyst as a Function of Temperature, SV 50,000 1/h, Feed Ratio = 1.0, at max. NH3 Storage.

## V. CONCLUSION

SCR and LNT applications will be developed for market introduction to address increasingly stringent current and future exhaust emission standards. Both technologies provide specific advantages and disadvantages and are based on the following individual parameters:

1) Package conditions.
2) Vehicle size.
3) Ratio between engine displacement and vehicle mass.
4) Test cycle.
5) Required NOx conversion efficiency.

One of the technologies or a combination of the two will be the optimum choice for each selected vehicle application. General considerations and simulations for specific applications illustrate that SCR is the preferred technical solution for heavy vehicle applications targeting the U.S. Tier 2 Bin 5 emission limits, whereas LNT technology is an alternative option for lighter vehicles.

A major challenge in the future for LNT technology is desulfurization and thermal aging and thus the long-term stability. Conversely, system packaging in the vehicle including the required SCR catalyst, tank volume and the low temperature activity will be important issues to be solved for SCR technology.

A second considerable challenge remains, which is the issue of the infrastructure for the urea distribution, especially in the U.S. The concerns of the EPA regarding this technology remain and have to be addressed by each manufacturer that attempts to launch a diesel vehicle in the U.S. using SCR exhaust aftertreatment.

In this way we understand the importance of emission regulations and their effects and how to overcome the problem of excess pollutants released from the exhaust of diesel engine and learned the Particulate Matter and NOx exhaust aftertreatment system which can be used to reduce the pollutants and the total process with a simulation.

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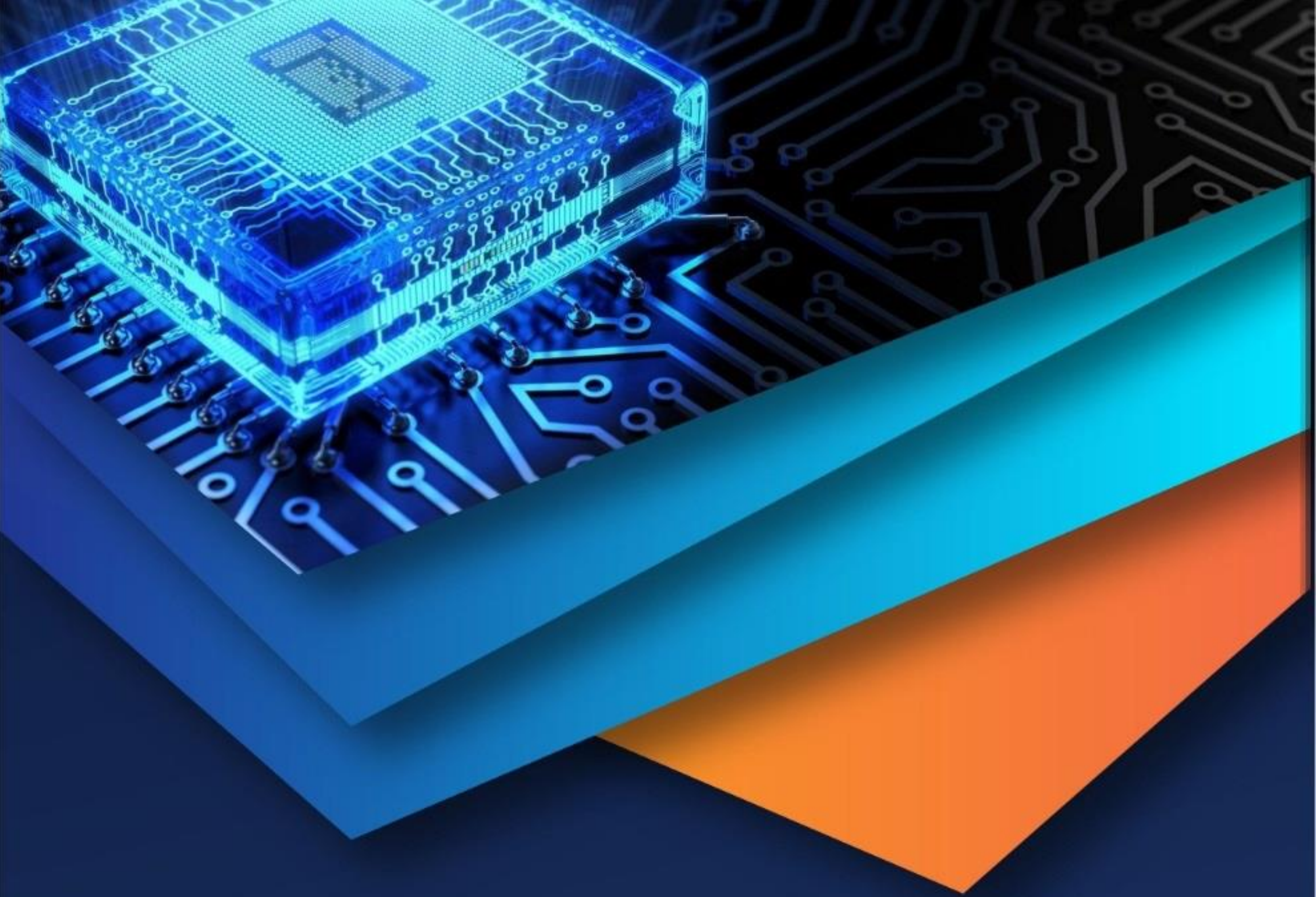

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