SELECTIVE CATALYTIC REDUCTION FOR HEAVY DUTY VEHICLES TO MEET Euro 4 AND 5 EMISSION LEGISLATION.

Selective Catalytic Reduction (SCR) provides efficient control of oxides of nitrogen (NOx) from Heavy Duty diesel engines whilst permitting the engine manufacturer to minimise particulate mass (PM) emissions and optimise fuel consumption.

Whereas previous emission limit values could be met by primary engine control measures the limits for PM and NOx in 2005/06 (Euro 4) and 2008/09 (Euro 5) respectively represent an extraordinary challenge for the developer of Heavy Duty (truck and bus) diesel engines. Due to the thermodynamics of the Diesel combustion process an engine design can only be optimized either in respect of NOx or of PM, but not both simultaneously NOx optimized engines offer less opportunity to optimise fuel efficiency and CO_2 emissions [1].

A highly fuel efficient engine optimized for low PM will have significantly higher engine-out NOx levels, but in combination with an SCR system has the potential to achieve very low NOx emissions without degrading diesel fuel efficiency. European vehicle manufactures have selected SCR technology as the best method to reduce the NOx emissions from diesel engines. This was confirmed in a statement issued by the European automobile manufacturers association (ACEA) on 15 July 2003 [2]. ACEA says that SCR technology will enable their members to comply with the Euro 4 and 5 emission standards and, at the same time, achieve fuel consumption levels which are 5 to 6% lower than those of equivalent EU 3 engines.

Selective Catalytic Reduction is one of the most efficient technologies to reduce nitrogen oxide emissions from all combustion processes, including vehicles [1]. This technology is already widely used in stationary diesel engines and power plants. A reducing agent such as urea is converted to ammonia and using the SCR catalyst NO and NO_2 are reduced to nitrogen and water. A clear, non-toxic, non-hazardous aqueous urea solution with 32.5% by weight urea ("AdBlue™") will be the reducing agent for on-road applications in the future.

The **infrastructure** for the reducing agent is already being addressed (in collaboration with the vehicle and engine manufacturers) by the reagent suppliers and by the fuel industry who will take care of any fluid that vehicles may require. Tanks and dispensers are available for installation at truck operators' premises and service stations. The activities of a joint working group headed by the German VDA (Verband der Automobilindustrie - the German Association of the Automotive Industry) has led to the establishment of norm DIN 70 070 which defines the properties of the AdBlue™, with the intention that this will become a European Standard (EN). Besides defining the reducing agent, there are additional efforts to characterize the properties and behaviour of this liquid [3], [4], [5].

For a mobile application, in which the operating conditions change rapidly (transient operation) an advanced **dosing system** for the reducing agent is necessary to provide the correct amount of reductant during all driving conditions. Additional requirements for using the SCR technology in vehicles are long term mechanical and thermal stability of the catalyst - to meet the future stages of emission legislation, the entire system has to comply with high durability requirements. Additionally, On-Board Diagnostics (OBD) methods have to be established to monitor the system and – in the case of failure – give and store a detailed report for surveillance and repair purposes. There are several options for monitoring an SCR system in a truck.

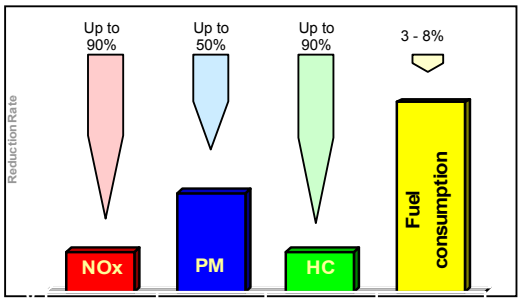
The most effective one is the use of gas sensors, particularly **NOx sensors**, downstream of the catalytic system. This type of sensor has been introduced in serial production in European passenger car applications with a NOx storage catalyst in mid 2002, where it is suitable for the measurement of engine-out NOx-emissions as well as for the OBD of NOx control devices. The so-called "smart NOx-sensor" is a stand-alone component with data link for easy integration in the

Av. de Tervueren, 100 **Tel. : 32.2.743.24.90** **E-mail: info@aecc.be**
B-1040 Bruxelles **Fax. : 32.2.743.24.99** **Website: www.aecc.be**

engine management system or in the exhaust gas treatment system [6]. The more compact electronic module of the second sensor generation adapted to the specific requirements of the control of the NOx-sensor has now been introduced in production; specific designs of the sensor element adapted for light and Heavy Duty trucks as well as 12V and 24V versions are available. The use of a NOx sensor gives 'closed loop' control of the complete system as any failure or tampering (for instance disabling of the urea injector or the use of an incorrect fluid in the AdBlue™ tank) will result in the sensor detecting a change in NOx levels.

In addition **urea sensors** to detect the presence, concentration and level of AdBlue™ in the tank are in development and are expected to be in series production by the end of 2004. Flow sensors to monitor the delivery of the reducing agent to the injectors are also being developed. The engine and vehicle manufacturers are elaborating methods to ensure that the driver of the vehicle is unmistakably alerted to any system failure, including the need to re-fill the tank, and to minimise the opportunity for vehicle operation in such a malfunction condition.

The complete vehicle SCR system thus offers the potential for efficient control of NOx emissions with a high level of confidence in its operation.



Depending on the type of system used, the application of SCR systems can also offer a benefit for both PM and HC reductions. The PM reduction ability of the SCR catalyst could thus provide for a reliable compliance with the PM limit values of a PM optimized engine.

Beyond this, the combination of the SCR technology and a Diesel Particulate Filter (DPF) to combine the advantages of both techniques is also feasible.

AECC has performed a **test programme** [7], [8] to support the European Commission review process of the technical feasibility of the 2008 heavy-duty diesel emission standards. A combined emission control system of Catalyst-Based Diesel Particulate Filter (CB-DPF) and urea-based Selective Catalytic Reduction (SCR) catalyst, with an ammonia clean-up catalyst, has been applied to a series production Euro 3 medium-duty diesel engine. The results showed that the 2008 emission limits (Euro 5) are achieved with a 50% safety margin. NOx sensors before and after the SCR catalyst worked reliably throughout the project.

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[2] ACEA Statement on the Adoption of SCR Technology to Reduce Emissions Levels of Heavy-Duty Vehicles. ACEA Position Paper, 15 July 2003
http://www.acea.be/ACEA/20030630PositionPaperUREA.pdf

[3] AdBlue as a Reducing Agent for the Decrease of NOx Emissions from Diesel Engines of Commercial Vehicles, DMGK Report 616-1, Hamburg, 2003.
http://www.dgmk.de/downstream/report_616-1_d.pdf
http://www.dgmk.de/downstream/report_616-1_e.pdf

[4] DMGK Report 616-2, (publication expected for mid 2004)

[5] Koebel, M., Strutz, E.O.: Thermal and Hydrolytic Decomposition of Urea for Automotive Selective Catalytic Reduction Systems: Thermochemical and Practical Aspects; Ind. Eng. Chem. Res. 2003, 42, 2093-2100.

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