SELECTIVE CATALYTIC REDUCTION FOR HEAVY-DUTY AND LIGHT-DUTY VEHICLES.

Selective Catalytic Reduction (SCR) provides efficient control of nitrogen oxides (NOx) from 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 from heavy duty engines in 2008/09 (Euro V) and diesel passenger cars in 2014/15 (Euro 6) represent a challenge for the developers of diesel engines and vehicles. Due to the thermodynamics of the Diesel combustion process, it is difficult to optimise the combustion process for both NOx and PM emissions simultaneously. Moreover, NOx optimised engines offer less opportunity to optimise fuel efficiency and CO_2 emissions [1].

A highly fuel efficient engine optimised 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. Most European vehicle manufacturers have selected SCR technology as the best method to reduce the NOx emissions from heavy-duty 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 IV and V emission standards and, at the same time, achieve fuel consumption levels 5 to 6% lower than those of equivalent EU III engines. It has also demonstrated the potential for even lower emissions to meet future Euro VI limits [3]. In addition, manufacturers are now starting to launch light-duty vehicles using this technology [4].

Selective Catalytic Reduction is an efficient technology to reduce nitrogen oxide emissions from combustion processes, including vehicles [1]. This technology was initially used in stationary diesel engines and power plants but is now also finding application in both on and non road vehicles to decrease emissions. A reducing agent such as urea is hydrolysed into ammonia and, through the action of an SCR catalyst, the ammonia reduces NO and NO_2 to nitrogen and water. Careful control of urea addition ensures all the ammonia is used in the reaction, but where high levels of NOx conversion are required, an ammonia slip catalyst can be placed downstream the SCR catalyst to avoid any emissions of ammonia at the exhaust tailpipe. A clear, non-toxic, non-hazardous aqueous urea solution with 32.5% by weight urea ("AdBlue®") is the current reducing agent for on-road applications. Alternative fluids and solids are also under development.

The **infrastructure** for the reducing agent has been addressed by the reagent suppliers and by the fuel industry in collaboration with the vehicle and engine manufacturers. 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®, and this is now being developed as a European Standard (EN). Besides defining the reducing agent, there are additional efforts to characterize the properties and behaviour of this liquid [5], [6], [7]. European

Diamant Building
Boulevard Auguste Reyers 80
B-1030 Brussels
Belgium

Tel. : +32.2.706.81.60
Fax. : +32.2.706.81.69
E-mail: info@aecc.eu
Website: www.aecc.eu

AdBlue® pumps can be found at www.findadblue.com. Smaller packagings of 1 to 2L bottles of AdBlue® are also being developed.

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. The AdBlue® solution is an eutectic solution of urea and freezes at -11°C, therefore full time operation of the SCR system requires a heating strategy in very cold parts of the world. Vehicle SCR technology has to comply with long term mechanical and thermal stability requirements including the catalyst. On-Board Diagnostics (OBD) methods are being established to monitor the system and, in the case of malfunction, give and store a detailed report for surveillance and repair purposes. There are several options for monitoring an SCR system on a vehicle.

Monitoring the status of the system through the use of gas sensors, particularly **NOx sensors**, provides an effective option to ensure correct function of the SCR 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 was used to measure engine-out NOx-emissions as well as diagnose the efficiency for NOx control. The so-called "smart NOx-sensor" is a stand-alone component with data link for easy integration in the engine management system or in the exhaust gas treatment system [8]. 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 vehicles as well as 12V and 24V versions are available. The use of a NOx sensor allows '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 have been introduced in series production in 2004. **Ammonia sensors** are also under development together with **flow sensors** to monitor the delivery of the reducing agent to the injectors. Engine and vehicle manufacturers are developing methods to ensure that the driver of the vehicle is alerted to any system failure, including the need to re-fill the tank, and to minimise the opportunity for vehicle operation with a malfunctioning emission control system.

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

In addition, the combination of the SCR technology with a Diesel Particulate Filter (DPF) allows the simultaneous reduction of both NOx and PM emissions.

In 2007, AECC completed a **test programme** [3] to evaluate the technical feasibility of the European Commission's proposals for future Euro VI legislation by demonstrating the emissions potential of an integrated emissions control system combining Diesel Particulate Filtration with Selective Catalytic Reduction applied to a commercially-available US2007 low-NOx engine. This work provided a follow-up to AECC's previous Heavy-duty demonstration programme conducted in 2002 [9], [10], using a Euro III engine, which already achieved emissions of half the Euro V limits after 1 000 hours test-bed ageing (equivalent to 250 000km) when fitted with a similar system.

The results obtained from the AECC Heavy-duty Euro VI program showed NOx emissions of 0.150g/kWh over the European Transient Cycle (ETC). The system efficiency for NOx reduction was 86% on the ETC test, confirming the efficiency of an integrated NOx and particulate reduction system when applied to a low-NOx engine. NOx sensors before and after the SCR catalyst worked reliably throughout both projects.

[1] Wuensche, P., Moser, F. X., Dreisbach, R., Sams, T.: "Can the technology for Heavy Duty diesel engines be common for future emission regulations in USA, Japan and Europe?", SAE Paper No. 2003-01-0344

[2] ACEA Statement on the Adoption of SCR Technology to Reduce Emissions Levels of Heavy-Duty Vehicles. ACEA Position Paper, 15 July 2003

[3] May J., Bosteels, D. Nicol A., Andersson J. Such C.: "The Application of Emissions Control Technologies to a Low-Emissions Engine to Evaluate the Capabilities of Future Systems for European and World-Harmonised Regulations" 16. Aachener Kolloquium Fahrzeug- und Motorentechnik 2007 http://www.aecc.eu/content/pdf/AECC_PAPER_for_Aachen_Final_20070716.pdf

[4] http://www3.mercedes-benz.com/techlex/2007/main_en.html

[5] 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

[6] AdBlue as a Reducing Agent for the Decrease of NOx Emissions from Diesel Engines of Commercial Vehicles, Part 2: Laboratory and Field Testing of AdBlue - AdBlue Logistics, DMGK Report 616-2, Hamburg, February 2005
http://www.dgmk.de/downstream/report_616-2%20_d.pdf
http://www.dgmk.de/downstream/report_616-2_e.pdf

[7] 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

[8] Kato, N., Kokune, N., Lemire, B., Walde, T.: "Long Term Stable NOx Sensor with Integrated In-Connector Control Electronics". SAE Paper No. 1999-01-0202

[9] Andersson J.D., Jemma C.A., Bosteels D., Searles R.A.: "Particle Emissions from a EU 3 Heavy-duty Diesel Engine with Catalyst-based Diesel Particle Filter and Selective Catalytic Reduction System: Size, Number, Mass & Chemistry". Aachener Kolloquium Fahrzeug- und Motorentechnik 2002
http://www.aecc.eu/content/pdf/Ricardo%20AECC%20Paper%20Aachen%202002%20final.pdf

[10] Searles R.A., Bosteels D., Such C.H., Nicol A.J., Andersson J.D., Jemma C.A.: "Investigation Of The Feasibility Of Achieving Euro V Heavy-Duty Emissions Limits With Advanced Emission Control Systems". FISITA 2002 World Automotive Congress.
http://www.aecc.eu/content/pdf/FISITA%20F02E310-PAPER.pdf