Bluetec – The Concept for Diesel Engines with Lowest Emissions

In October 2006 when Mercedes-Benz introduced the model E 320 Bluetec, it brought the first production diesel passenger car to the market that met US Tier 2 Bin8 emission standards. Mercedes-Benz will continue its Bluetec offensive in 2008, offering the V6 diesel engine in the M, GL and R Classes in the USA, using the SCR/AdBlue technology which meets the US Tier 2 Bin5 emission standards and thereby all currently valid emission standards for diesel passenger cars worldwide.

1 Introduction

In these times of rising fuel costs and a growing sensitivity to CO_2 emissions, the diesel engine has proved itself on the market as an attractive alternative to the gasoline engine. The reason for this, besides its high efficiency, is the fact that new technologies such as turbocharging and direct injection, e.g. with common rail, allow increasing peak performance and torque values at a very high level of convenience. Today, every second new passenger car in Europe is fitted with a diesel engine.

Until now, it was mainly the US emission laws that prevented a similar success for diesel engines in the USA. In spite of this, Mercedes-Benz opened the door to the US passenger vehicle market for diesel engines in 2004 with the E 320 CDI (Bin10). This strategy was continued in a newly developed Mercedes-Benz technology called Bluetec, leading to the introduction of the E 320 Bluetec in the US in 2006. This was the first production diesel passenger car to meet the US Tier 2 Bin8 standards. This technology has also been available in Europe in the E 300 Bluetec since the end of 2007. In 2008 this will be followed by the R, ML and GL 320 Bluetec, the first three diesel SUVs in the world to meet the strict Tier 2 Bin5 norm for 50 US States, which also will have the potential to meet the planned EU6 emission standard.

2 The Bluetec System

Bluetec technology, **Figure 1**, incorporates the base engine with minimised engine out emissions, the treatment of exhaust gases with an oxidation catalytic converter, particulate filter and aftertreatment of nitrous oxides, as well as a control system that coordinates the various components and operating modes. Nitrous oxides are treated using either a NO_x storage catalytic converter or an SCR system (Selective Catalytic Reduction) with AdBlue, an aqueous urea solution, which releases the reducing agent ammonia.

3 Engine Out Emission Reduction

For use in the Bluetec model, the V6 engine with the in-house identification OM 642 was thoroughly overhauled. The objective of the modifications was the minimisation of raw emissions as well as meeting the legal requirements for onboard diagnostics (OBD).

The performance and torque of the OM 642 V6 engine, which is also used in the E 300 Bluetec in Europe [1], are displayed in **Figure 2**.

The following alterations were made to the familiar EU4 model for the European market:

– Reduction of the compression ratio from 17.7 to 16.5 as well as modified piston geometry

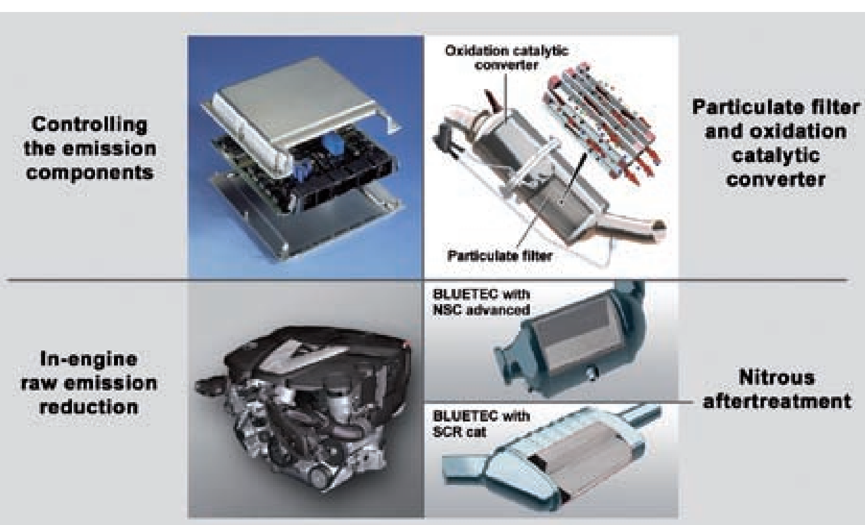


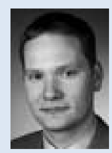
Figure 1: The Bluetec system's components

The Authors

Dr.-Ing. Joachim Schommers is Director Development Passenger Car Diesel Engines at the Daimler AG in Stuttgart (Germany).

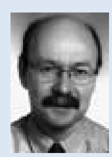
Dr.-Ing. Andreas Zygan is Director Body Development Exterieur/Interieur S/SL/SLK Class at the Daimler AG in Sindelfingen (Germany).

Dipl.-Ing. Ralf Binz is Senior Manager Calibration Diesel Engines at the Daimler AG in Sindelfingen (Germany).



Dipl.-Ing. Dietmar Eckert is Manager Development Exhaust Systems Diesel Engines C/E Class at the Daimler AG in Sindelfingen (Germany).

Dipl.-Ing. Markus Paule is Manager Diesel Exhaust Aftertreatment and Project Bluetec Bin5 at the Daimler AG in Stuttgart (Germany).



Dr.-Ing. Stephan Reichel is Manager Combustion Passenger Car Diesel Engine OM 642 USA at the Daimler AG in Stuttgart (Germany).

Dipl.-Ing. Karl-Heinz Kempka is Senior Manager Large Car Lines, Exterieur, Fuel Systems at the Daimler AG in Sindelfingen (Germany).

Table: Engine main specification

		OM 642 3.0 l *M / R Class BIN5*	OM 642 3.0 l *M / R Class BIN10*	OM 642 3.0 l *M / R Class EU4*
Transmission	–		7-gear automatic	
Cylinders	–		V6	
Bank angle	–		72°	
Valves / cylinder	–		4	
Capacity	cm^3		2987	
Bore	mm		83	
Lift	mm		92	
Cylinder spacing	mm		106	
Compression ε	–	16.5	17.7	17.7
Nominal performance at rpm	kW / hp /min	156.5 / 210 3400	160 / 215 4000	165 / --- 3800
Nominal torque at rpm	Nm / ft-lb /min	543 / 400 1600 - 2400	543 / 400 1600 - 2400	510 / --- 1600 - 2800
Engine weight	kg		208	

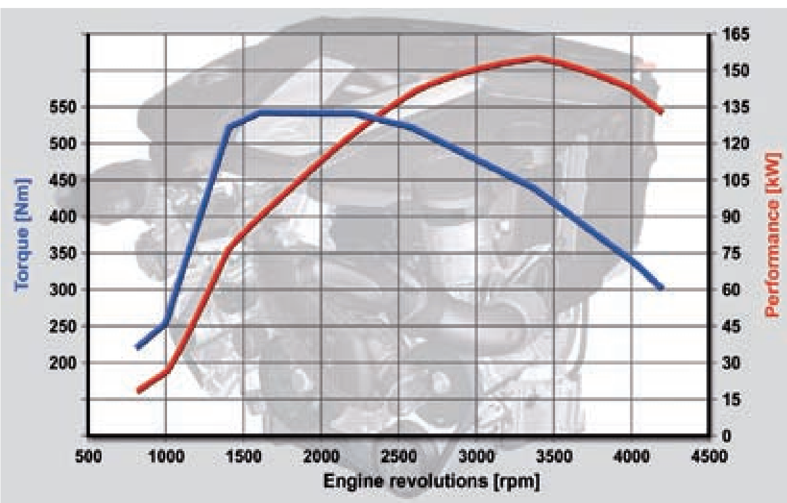


Figure 2: Performance and torque of the V6 OM 642 Bin5/Bin8 diesel engine

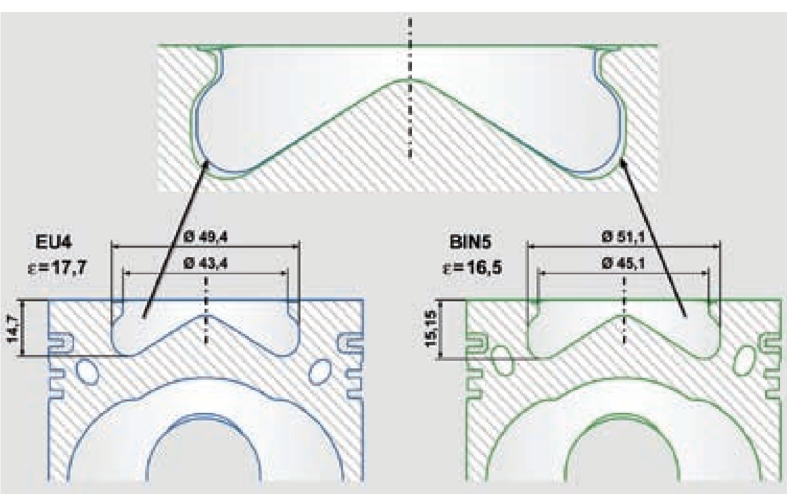


Figure 3: Comparison of the piston bowl on the EU4 to Bin5/Bluetec

- use of a specifically adapted injector
- increase in EGR cooler performance by 20 %
- optimised VNT exhaust gas turbocharger
- OBD monitoring of the glow system, the intake port shutoff and the EGR cooler
- utilisation of a more powerful generation of engine controller
- additional functions to optimise EGR regulation.

The engine is only offered in conjunction with the seven-gear automatic transmission (7G-Tronic). The engine performance is 156.5 kW, the torque is 543 Nm. The **Table** shows the main characteristics of the OM 642 Bin5 compared to the exhaust models EU4 and Bin10.

Compared to EU certification, in order to receive a US certificate in the various exhaust cycles (FTP, US06, SC03), operating ranges are tested right up to full throttle. All relevant parameters were systematically analysed with the help of DOE tools (design of experiments) to optimise raw emissions, fuel-consumption and NVH behaviour.

3.1 Optimising the Combustion System

Figure 3 shows the new piston form with a larger bowl in comparison to the initial piston of the OM 642 engine for EU4. A significant increase in EGR compatibility was achieved in conjunction with an injection nozzle with a significantly reduced flow rate to produce a better mixture. An optimised mixture preparation was obtained using a seven-hole nozzle.

In order to meet raw emission goals over the entire lifecycle of the engine and taking into consideration the tolerances of components relevant to emissions, the following concept proposals were chosen to support mixture formation:

- Direct controlling of the EGR rate
- learning the real, individual filling behaviour in operation
- additional correction of the air mass measurement
- learning the dispersion and drift of the injection quantity.

The selected EGR rate model, which consists of three temperature models and a filling model, is shown in **Figure 4**. Precise engine management to narrow the emission dispersion range can

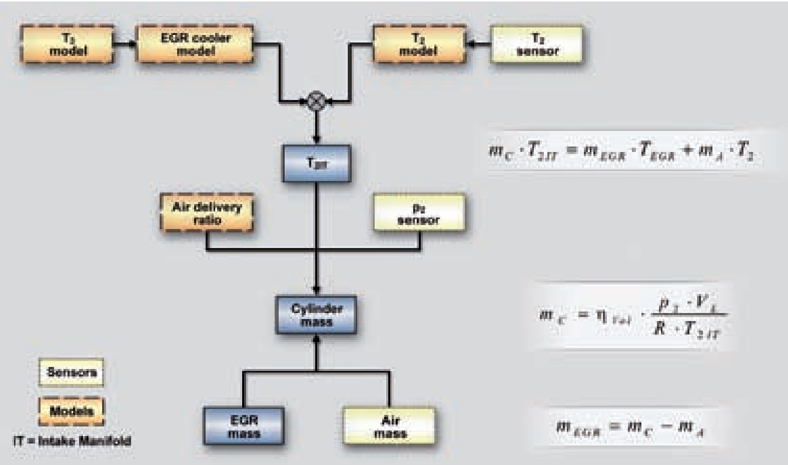


Figure 4: EGR rate calculation model

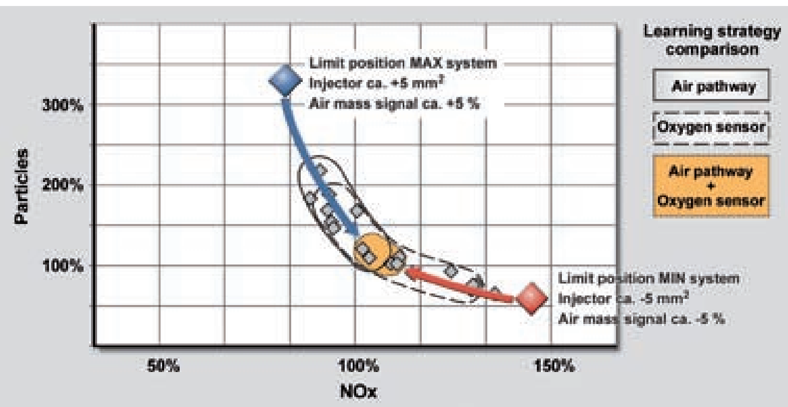


Figure 5: Emission programming quality

only be guaranteed if delivery air ratio, air mass and injection quantity are precisely determined. That is achieved via a permanent "learning triangle", resulting from networking and coupling learning functions like delivery air ratio adjustment and HFM drift compensation as well as an injection correcting function using the oxygen sensor signal [2].

With the aid of these learning and control functions, limit systems (formed by HFM and injector drift) can be learned properly and raw emission scatter can be reduced significantly, **Figure 5**.

3.2 Improved Turbocharging

High EGR rates on the one hand, and high emission sensitivity to minimum variations in EGR rate on the other required improvements to the charging design especially in terms of regulation stability. Therefore, the newest generation of exhaust gas turbocharger with variable turbine geometry was chosen, **Figure 6**.

Unlike its predecessor, the adjustment mechanism is fixed at the bearing housing on this turbocharger and decoupled from the turbine housing, the guide blade profile is curved and the turbine wheel geometry is provided with a closed wheel back. As a result, this new generation exhaust gas turbocharger excels, not only with its improved thermodynamic properties, but also due to its very low adjustment hysteresis. This made it possible to make stable adjustments to EGR rates and charge pressure under any constraints.

3.3 New Engine Controller Generation EDC17

With the introduction of Bluetec technology in the USA a number of additions to engine management were necessary:

- Integration of additional sensors and actuators for USA BIN5 (NO_x sensors, temperature sensors, pressure sensors)
- integration of OBDII circuits for engine, oxidation catalytic converter, particulate filter and SCR catalytic converter, SCR tank system and level sensors
- implementation of SCR metering strategy and quantity adjustment
- implementation of a warning and display concept for the SCR system
- further development of engine learning and control functions.

Because of these necessary additions, the efficiency of the previous control module platform EDC16 (EDC: Electronic Diesel Control) was no longer suffi-

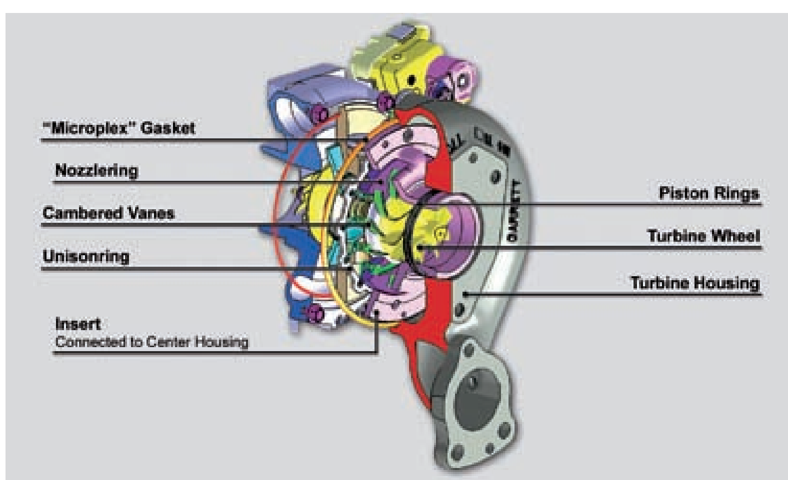


Figure 6: Exhaust gas turbocharger OM 642 US version

cient. An upgrade to the EDC17 platform was necessary. The EDC17 platform is based on the Infineon TricoreTC1796 Metis processor with 150 MHz clock frequency and 2MB internal flash storage, **Figure 7**.

Furthermore, with the introduction of the EDC17 platform the following goals were achieved:
- Common architecture for diesel and gasoline vehicle control modules
- optimised CAN architecture
- use of Daimler in-house software
- 12-bit AD converter on-chip for temperature sensors
- reduction of hardware costs
- reduction in installation space.

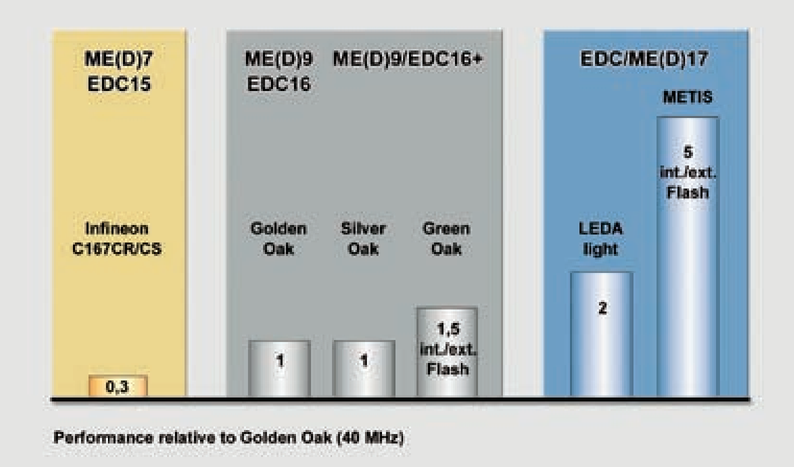


Figure 7: Performance comparison of the engine controller platforms

4 Aftertreatment of Exhaust Gas

The following three reduction technologies were analysed and evaluated as part of the development of Bluetec strategies for NO_x aftertreatment:
- The HC $DeNO_x$ method, where HC components in non selective catalytic converters are used for NO_x reduction
- NO_x storage catalytic converters, which were already familiar in principle from lean-run gasoline engines
- SCR (Selective Catalytic Reduction) - technology using ammonia as a reducing agent, which can be implemented for example with AdBlue, an aqueous urea solution.

Figure 8 shows in the results of the evaluation that these technologies vary greatly in their effectiveness:
- The HC $DeNO_x$ method has only a very narrow effective temperature window and a relatively low conversion rate
- the NO_x storage catalytic converter (NSC advanced) covers a much greater temperature range, but is also more sensitive to ageing than
- SCR technology, which also provides the highest conversion potential of all applications [3, 4].

4.1 The Exhaust System with NSC advanced

The exhaust system shown in **Figure 9** has been in use since October 2006 in the E 320 Bluetec in the USA as well as in the E 300 Bluetec in Europe since December 2007. It consists of an oxidation catalytic converter close to the engine, followed by a NO_x storage catalytic converter. The particulate filter is in the underbody. At the end of the front system, there is an additional catalytic converter. It has a special SCR coating to improve NO_x reduction even further and to guarantee long-term stability of the entire system.

Similar to the storage of nitrous oxides, the NO_x storage catalytic converter also stores sulphur oxides and the chemical bonding of the sulfates to the metal components of the NO_x storage catalytic converter is even stronger than the bonding of nitrates. Therefore a precondition for NO_x reduction using NO_x storage catalytic converters is the availability of sulphur-free diesel fuel. But even then the storage space is taken up by sulphate, as although the amount of sulphur is limited, it is still present in this fuel. So a desulphation needs to be carried out on the NO_x storage catalytic converter from time to time. A certain combination of the parameters of temperature, stoichiometry and duration of the desulphation needs to be chosen so that the storage catalytic converter is not damaged due to high temperatures, while maintaining the temperature at a sufficient level to enable it to remove sulphate from the storage catalytic converter. In the E 320 Bluetec application, these desulphation conditions are successfully reached during a DPF regeneration.

4.2 The Exhaust System with SCR Catalytic Converter and AdBlue Injection

Figure 10 describes the Bluetec exhaust system as it will be offered in the M, GL and R Classes as a Bin5 solution in the USA from 2008. Compared to a Bin10/EU4 exhaust system, an additional SCR

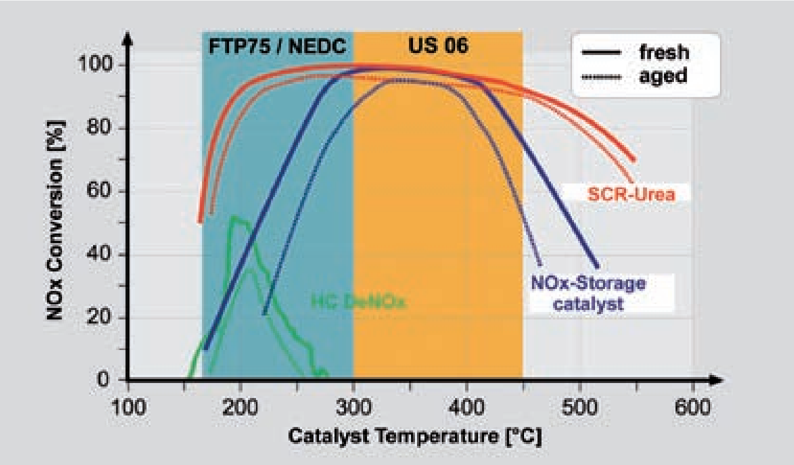


Figure 8: Conversion rates of various NO_x reduction technologies

catalytic converter is necessary in the underbody, along with the AdBlue dosing valve, additional temperature sensors and also NO_x sensors to regulate the AdBlue injection and diagnostics.

4.3 The AdBlue Supply System

The urea solution is stored in a separate tank in the vehicle and transported from there via a delivery pump to the dosing module. AdBlue dosing systems were familiar as early as 2004 for their use in Mercedes-Benz commercial vehicles in Europe to allow them to meet the Euro 4 and Euro 5 standards. Despite this extensive experience in commercial vehicles, further challenges had to be faced before it could be used for passenger cars in the USA:

- Improvement of the cold-start capability of the dosing system
- high temperature stability of the dosing system and SCR catalytic converter in combination with a particulate filter
- optimisation of the NO_x reduction strategy using NO_x sensors and intelligent, self-learning software functions in the engine control module
- fulfilment of the OBD II law by monitoring the dosing system and NO_x sensors
- special injection strategy for passenger vehicle use
- packaging and heating strategy for the AdBlue tank in the vehicles
- optimisation of the NH_3 distribution in the exhaust flow after injection.

AdBlue is stored in a separate tank in the rear of the vehicle. This can be on the underbody or in the spare wheel recess, depending on the type of vehicle.

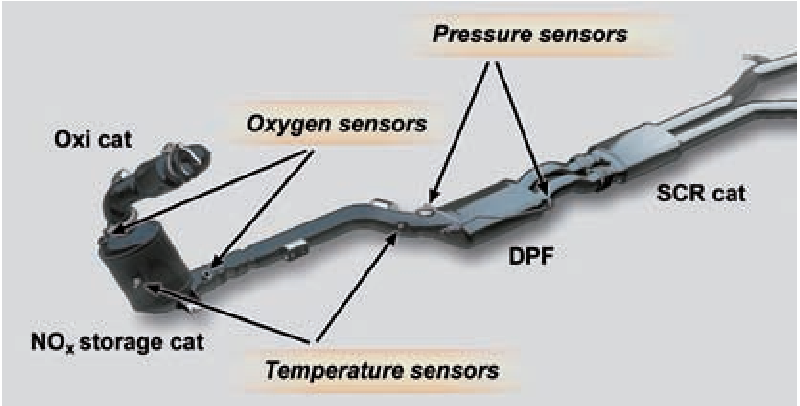


Figure 9: Bluetec exhaust system with NSC

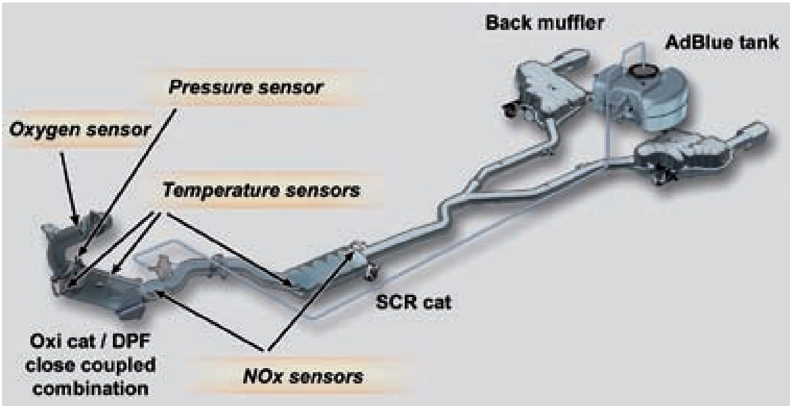


Figure 10: Bluetec exhaust system with SCR

Figure 11 shows exemplary an AdBlue tank with its interfaces and components. The tank includes an integrated delivery module with diaphragm pump, switching valve, 4/2-way valve and heating as well as a pressure and a temperature sensor.

As a 33 % urea solution freezes at 262 K (-11 °C), while functionality must be guaranteed far below freezing point, the urea tank contains a heating element. The supply line to the dosing valve and all connectors are also heated. This design allows AdBlue to be supplied after brief operation of the vehicle even when the tank is completely frozen.

The urea tank is refilled by Mercedes-Benz on a regular basis in line with the service. This way the customer has no contact with another operating fluid. To facilitate this, the urea tank capacity is designed such that even customers with higher AdBlue consumption due to higher load demands (e.g. towing a trailer) do not have to make an unscheduled stop at the workshop. If contrary to the expectations the AdBlue quantity has been used up early, the customer can make an emergency top-up using a refill bottle. The spe-

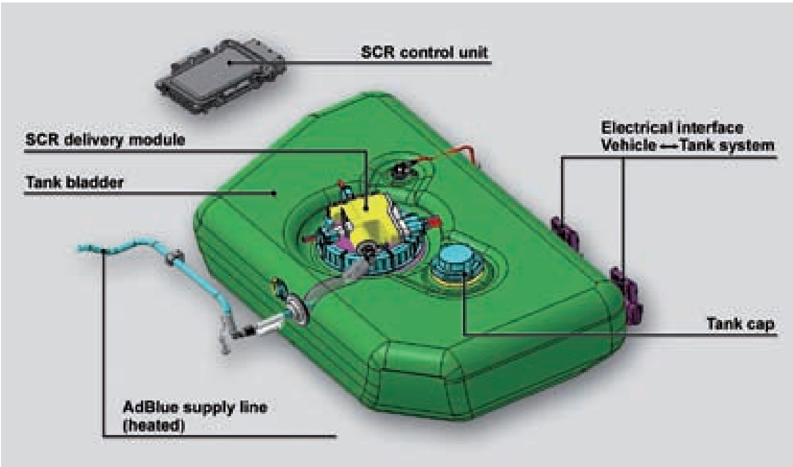


Figure 11: SCR supply system

cial bottle system ensures the tank can be refilled without spillage or inhalation.

AdBlue is injected in discrete amounts, while the ammonia reservoir in the SCR catalytic converter provides an ammonia reserve so that even between injections there is enough ammonia to reduce nitrous oxides. The dosage is controlled in a pattern; a NO_x sensor calibrates the ammonia storage modul for the SCR catalyst.

The structure of the dosing module is depicted in **Figure 12**. The module is air-cooled with a stainless steel heat sink. Heat is dissipated from the metering valve via a graphite sleeve package. The system pressure is 5 bar. The metering valve itself is a conventional 3-hole solenoid valve.

The metering valve, the mixing area between nozzle and catalytic converter as well as the flow to the catalytic converter must be so designed as to provide the most even distribution of ammonia in the SCR catalytic converter possible.

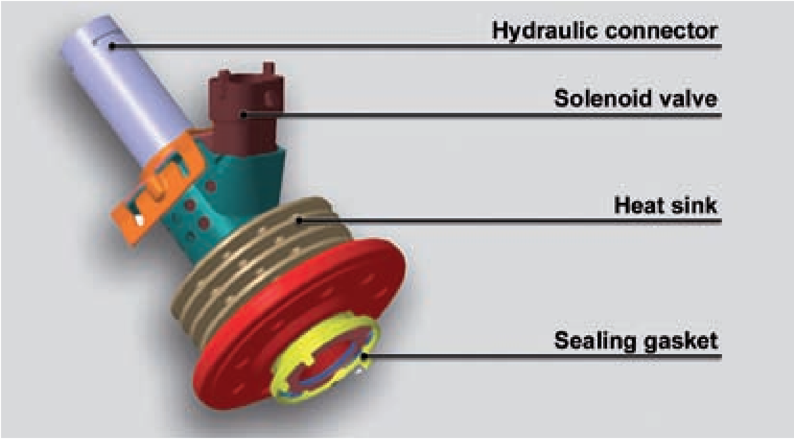


Figure 12: Dosing module (Source: Bosch)

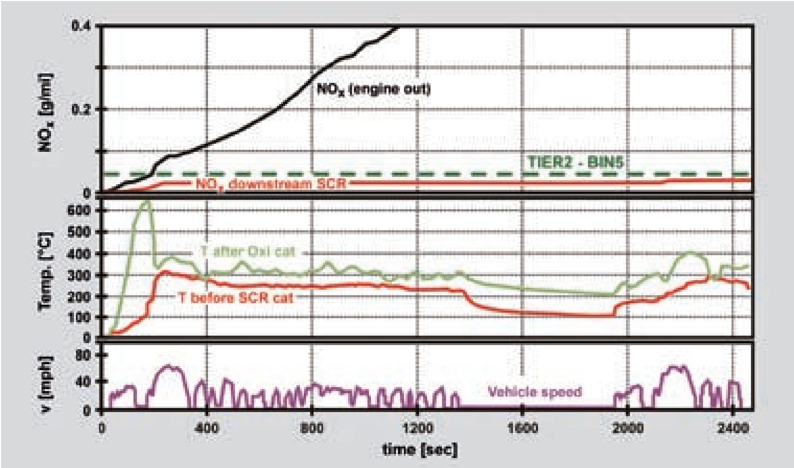


Figure 13: FTP 75 test results

5 Exhaust Application and FTP 75 Test Results

To guarantee functionality of the whole system over the entire lifecycle of the car, the system requires robust design, and may contain only catalytic converters (oxidation catalytic converter, particulate filter, NO_x storage or SCR catalytic converter) and a dosing system whose long-term stability is guaranteed. The oxicat and particulate filter system must be designed to reduce NMHC and CO to at least ULEV levels. If a particulate filter reaches a limit load of particles, the deposited soot particles must be heated until they are burned with the oxygen in the exhaust. This procedure starts at exhaust temperatures of between 600 °C and 650 °C. Finally, in certain operating conditions the SCR catalytic converter must be able to reach conversion rates of over 90 % during its full lifecycle.

To ensure these high standards of emission quality, numerous tests were carried out on-site under extreme conditions, the results of which have contributed to confirm the application and led to further optimisation. **Figure 13** shows the results of SCR NO_x reduction in the FTP 75 test. Once the SCR catalytic converter starts up, after approximately 250 seconds almost the entire NO_x raw emission has been reduced due to the high NO_x conversion rate. The other emission relevant exhaust components like NMHC, CO or particles are diminished by the oxicat and the particulate filter to a level way below the required limits.

6 Summary

With Bluetec, Mercedes-Benz has developed a key technology which has the potential to meet every emission standard in the world with passenger car diesel engines. The SCR system together with its additional AdBlue operating fluid has been evaluated as an effective, robust solution with long-term stability. Mercedes-Benz will introduce this technology in the SUV segment of the US market in 2008. The next steps will see the technology successively introduced in other vehicle production lines and in other markets.

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