Urea SCR Systems in Focus
New Challenges in the Development of Exhaust Systems

One of the main thrusts of development when it comes to exhaust systems with integrated SCR technology for cars and commercial vehicles lies in the area of urea processing before the SCR catalytic converter. In contrast to conventional exhaust systems with single-phase gas flow, the complex processes in this area call both for new development methods and new components in the exhaust system. For the SCR applications, Eberspächer has developed various mixers which significantly shorten the necessary mixing section and in some cases actually make possible the constructive use of SCR technology.

1 Introduction
SCR technology has been one of the main thrusts of development in the exhaust gas aftertreatment of commercial vehicles for a number of years. It is now becoming the focus in the diesel car too.

This development is being driven by forthcoming emission and immission limits in Europe and the USA which, particularly in relation to nitrogen oxides, constitute a major challenge [1].

In order to be able to guarantee compliance with these limits, especially with larger and relatively heavy vehicles, besides measures to reduce crude engine emissions, efficient NOx aftertreatment systems are also necessary. Here, selective catalytic reduction (SCR) exhibits the greatest potential for NOx reduction.

2 Working Principle
The basis of the SCR system, alongside the use of a suitable catalytic converter (based on vanadium pentoxide or zeolite structures) is the dosing of a suitable reduction
medium. For current vehicle developments an aqueous urea solution, marketed under the brand name AdBlue, has gained acceptance from among various alternatives. The urea, injected into the hot exhaust gas, is converted in the gas flow and on the surface of the following catalytic converter to ammonia. This ammonia is ultimately required on the SCR catalytic converter as a reacting agent for the nitrogen oxides.

A prerequisite for achieving high NO\textsubscript{x} conversion rates is the optimum processing of the injected urea solution in the exhaust system.

Alongside urea dosing technology, the design of the exhaust system also plays a very large role in the effectiveness of the SCR system. Inadequate urea processing leads inevitably to a decrease in NO\textsubscript{x} conversion and increased ammonia slip.

### 3 SCR Technology in Cars and Commercial Vehicles

Due to varying exhaust gas mass flow rates and dimensional specifications, the layout of car and commercial vehicle SCR systems differs considerably. For car applications, generally speaking single-flow systems are being developed at the present time. One or several coated SCR catalytic converters placed behind another come after the urea dosing unit. A particular challenge arises in current projects from the often very restricted dimensional specifications. In the development of the systems these require very specifically adapted solutions, especially in the area of urea processing.

For commercial vehicle applications, very compact aftertreatment systems are predominantly being developed for the European market. These are divided into several chambers which, besides gas diversion, also perform acoustic tasks. Due to the high mass flow rates, here either significantly larger substrates or several smaller substrates are built in parallel.

In addition to the fundamentally different layout concepts, the other system components, e.g. the dosing technology used, also differ very substantially between car and commercial vehicle applications. The reasons for this, besides significantly different dosing rates, include the availability of a compressed air supply.

Due to the differences mentioned, the solutions for the car and commercial vehicle layout concepts also differ significantly from one another. Common to developments for both types of system, however, is the fact that for the layout and establishment of the design new methods for assessing the system functions have to be developed. The primary focus here is on the improvement of urea processing through suitable mixer structures and the assessment of urea processing.

### 4 SCR Mixers

In order to optimise urea processing in the exhaust system Eberspächer has developed various mixers [2]. By way of example, the effect on conversion quality is shown in two mixer structures. Figure 1.

In extensive tests, both in-house as well as at various customer sites, both mixers have proven their potential for optimising urea SCR systems. Due to its compact shape, the helical ribbon mixer can be used in virtually all applications. Both mixers have already been subjected to durability tests and passed them without reservations [3]. In addition, both mixers represent a compromise between good urea distribution properties and an increase in counterpressure which is as low as possible.

### 5 Assessment of Urea Processing

Direct observation and recording of the complex processes following the injection of the aqueous urea solution, e.g. secondary atomisation effects, is under investigation. At the present time, for design development within the framework of normal development cycles, the following twin-track procedure is useful.

In the early phase, development takes place using virtual development tools. Due to the two-phase flow involving secondary atomisation and evaporation processes, this task is very complex for flow calculation and currently has relatively little predictive validity [2].

For this reason Eberspächer has developed different methods for the experimental assessment of the systems on the engine test bench.

The transient operation of SCR systems is very strongly influenced by engine and dosing system control. Potential weak points cannot always be recognised immediately.

Rapid recording of the distribution of the urea and its decomposition products present in front of the SCR catalytic converter is virtually impossible in measurement terms. Assessment of the urea processing must therefore be carried out indirectly using the distribution of the reaction products at the catalytic converter outlet.

For the analysis of the gas composition, gas samples are taken and, with the aid of a suitable sampling system, conducted to a gas analyser for the components NO, NO\textsubscript{2} and NH\textsubscript{3}.

For a purely global view of the conversion characteristics of the SCR catalytic converter, a sample probe can be positioned in the exhaust gas system upstream (before urea dosing) and also downstream. From such a measuring arrangement the mean NO\textsubscript{x} conversion rate and the mean NH\textsubscript{3} slip can then be determined. The measurement results however allow only very limited conclusions to be drawn regarding possible flaws in the distribution of the reduction medium onto the catalytic converter.

A local view of the concentration distributions is effective here. To this end, either a large number of gas sample probes must be installed permanently behind the catalytic converter, or a way must be found of moving a probe during measurement over the catalytic converter outlet surface.

For the description of urea processing, a key figure corresponding with the assessment value that is commonly used in exhaust system development was selected, into which the determined local gas concentrations ci via the cross-section of the monolith are incorporated (uniformity index for performance of urea distribution):

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y = 1 - \frac{\sum_{i=1}^{n} c_i \cdot e^l}{2n \cdot e^l}
\]

Eq. (1)

By allowing for local mass flow rates, e.g., gathered from the flow simulation, or surface-dependent evaluation during irregular scanning, the informational value with regard to the total level of emissions can be increased.

#### 5.1 Car SCR Systems

As the sample probe itself has a physical extension, the placing of many measuring probes in the output funnel of the catalytic converter unit leads to a significant effect on gas flow. Moreover, even with the use of e.g. multi-channel analysers, the number of possible measuring positions is considerably restricted.

Completely doing without the downstream part of the exhaust system leads, depending on the geometry of the funnel on the outlet side, to a change in the flow distribution even before the catalytic converter. On the other hand, this results in a high degree of freedom for positioning and...