

Veritas Blue-Liner[®] and SCR-Filling Systems



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SCR = Selective Catalytic Reduction

1. The Basics of Selective Catalytic Reduction

In reaction to the consistently rising number of motor vehicles leading to higher traffic density – in particular in metropolitan areas – legislators are required to impose ever stricter exhaust-gas limit values for new vehicles. As the number of diesel-powered cars has risen dramatically over the past years, particularly in Europe, the distinct reduction of nitrogen oxide limits for diesel engines is the most noticeable challenge. Further tightening of the EU air-quality guidelines has also considerably enhanced requirements on the automotive industry. These guidelines define the degree of contaminant concentration in the ambient air (immission) and the admissible particulate matter pollution. Considerably stricter nitrogen oxide limits have been in effect here since January 1, 2010.

As the enforcement and implementation of these legal requirements was no longer to be accomplished exclusively by optimizing combustion engines, automobile manufacturers were compelled to find new solutions. They opted for a solution model which had already been routinely applied in power-plant boiler systems to reduce pollution levels – this method is known as »selective catalytic reduction« [SCR]. It enables a selective chemical reaction at the catalyst primarily supporting reduction of nitrogen oxides without any undesired side effects occurring. As the reducing agent for motor vehicles is fluid, the system for storing and dosing the agent in motor vehicles must be similar to that for fuel supply to the engine.

Introduction of the Euro-6 standard for passenger cars brought with it that development of SCR systems in this domain has been intensified and has in part already been

implemented in series manufacture. The greatest differences between truck and car systems are the more complex structure of the latter owing to narrow installation space in the vehicle itself and car drivers' demands on service comfort. Further sophistication of SCR systems is also driven in general by the fact that maximum emission levels are being lowered by the European Union and throughout the entire world. Relevant international legislature are the rules and regulations enforced by the EU, CARB, EPA and Japan (p. 7).

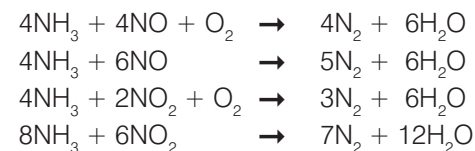
Reduction Process

- urea solution is injected upstream of the SCR-catalyst
- the reaction produces ammoniac
- the produced ammoniac blends with the exhaust gas / flue gas in the catalyst

Hydrolysis:



Reduction:



(at 200° - 400°C depending upon active component)

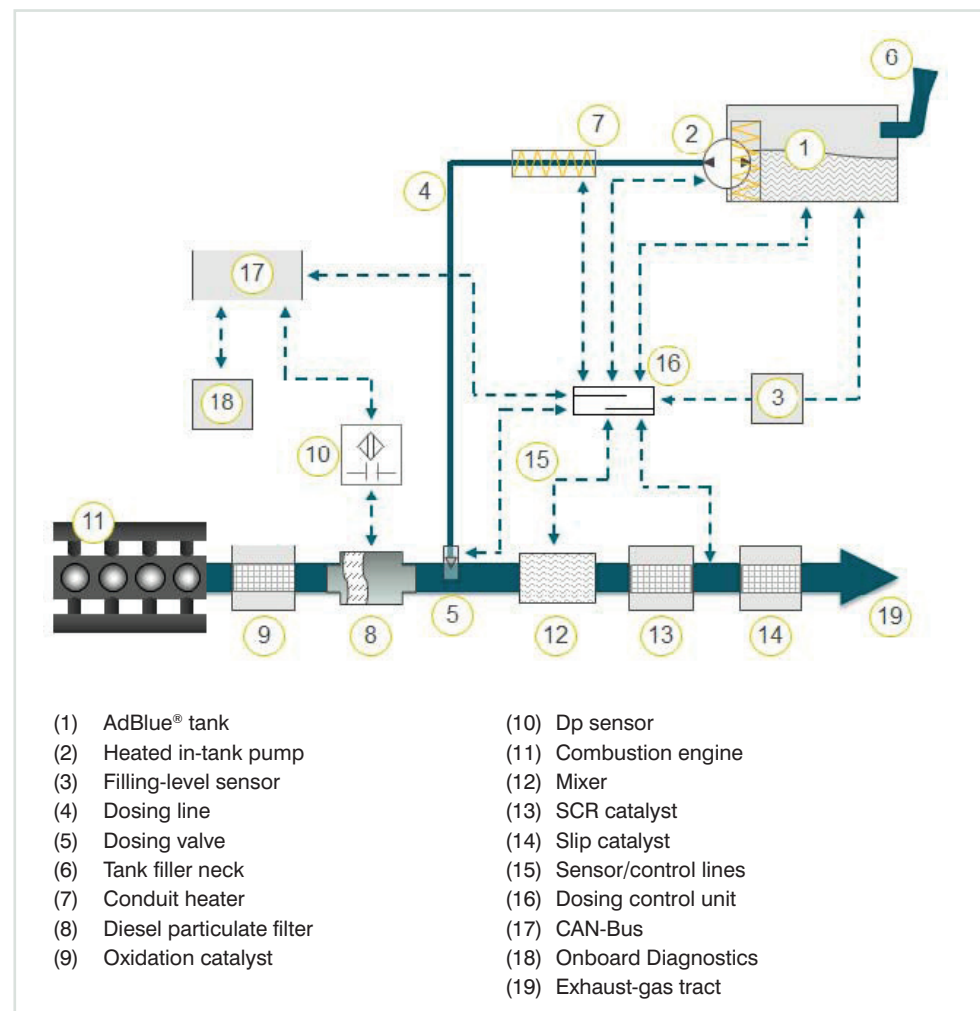
1.1 SCR Systems

Modern SCR systems such as those currently installed in diesel-fueled passenger cars operate on the basis of an aqueous urea solution being applied as reducing agent; such solution being known throughout the industry under the registered trade name AdBlue®. SCR systems may principally be structured into three function units:

- the system conducting the chemical substance
- the exhaust-gas tract
- sensors and control system

The detailed structure of the individual system units and of the entire SCR system is ultimately influenced and defined by the conditions particular to each vehicle. Fig. 1 shows the fundamental structure of an SCR system.

Fig. 1: SCR System



1.2 Liquid Conduit System

The liquid conduit system consists of an AdBlue® storage tank mounted, for example, in the spare-wheel well or the wheel case and with a filling capacity of between 10 and 35 liters, a bi-directional conveyor pump heated by the swirl pot, a filling-level sensor, a heated dosing line as well as the dosing valve integrated in the exhaust-gas tract. The storage tank is filled through the tank filler neck.

The tank inlet is located either in the trunk or in the fuel-tank pan next to the fuel tank filler neck. Special ventilation conduits and valves will compensate for pressure fluctuations in the system caused by changing temperatures, filling levels and driving conditions. This pressure compensation is required to make AdBlue® available as needed throughout all driving operations. The ventilation system is particularly important during storage-tank filling operations.

To be able to use the AdBlue® filling station infrastructure already available for trucks, the standard SCR system for cars is designed for a filling rate of up to 40 l per minute. To achieve this rate, the displaced air must at the same time be allowed to escape at the same rate.

1.3 Reduction Agent AdBlue®

Even if AdBlue® is the most commonly-used NO_x reducing agent in Europe, it has a number of shortcomings as relates to its properties. These include the high freeze point of -11.5 °C, the tendency to form solid residues if evaporation is retarded or the relatively low share in active ammoniac as compared to alternative reducing agents.

The essential chemico-physical properties of AdBlue® are:

- **high-purity transparent liquid**
- **32.5% urea in demineralized water**
- **density: 1.09 g/cm³**
- **freeze point: -11.5 °C (variation of volume 11 %)**
- **active ammoniac content per volume: 0.22 kg/l**
- **pH: 10**
- **high tendency to creep**
- **crystallization**
- **potentially unpleasant odors**



The great advantage of AdBlue® as compared to other liquid ammoniac precursor substances is that AdBlue® is not classified as hazardous material and that it is entirely harmless in physiological terms. As relates to its water polluting risk, it is allocated to the lowest water hazard category (class 1).

The quality requirements on AdBlue® are specified in ISO 22241-1 and DIN 70070.

2. Emission Laws and Regulations

In the past years, there have essentially been four regulatory models in effect which are applied in various manifestations in all threshold and industry countries.

CARB regulations > California; similar maximum levels apply in New York, Massachusetts, Connecticut, Vermont, Rhode Island, Maine, New Jersey

EPA legislature (Environmental Protection Agency) > applies to all other US states

EU legislature

Japan legislature

The following chart shows the laws in effect throughout the entire world as well as the time of their enactment.

Tab. 1: Emission Laws and Regulations

		2013	2014	2015	2016	2017	2018	2019	2020
Europe	Czech Republic	Euro 5				Euro 6			
	France	Euro 5				Euro 6			
	Germany	Euro 5				Euro 6			
	Hungary	Euro 5				Euro 6			
	Italy	Euro 5				Euro 6			
	Poland	Euro 5				Euro 6			
	Russia		Euro 4				Euro 5		
	Slovakia	Euro 5				Euro 6			
	Turkey		Euro 5				Euro 6		
	Great Britain	Euro 5				Euro 6			
China	Beijing				Euro 5				
	China		Euro 4			Euro 5			
	Taiwan				Euro 5				
Japan / Korea	Japan					Japan '09			
	South Korea	Euro 5				Euro 6			
Middle East/ Africa	Iran				Euro 2				
	South Africa				Euro 4				
North America	Canada			Tier II, Bin 4				Tier II, Bin 2	
	Mexico (gasoline)	Euro 4				Euro 5			
	USA			Tier II, Bin 4				Tier II, Bin 2	
	USA (California)					LEV III			
South America	Argentina				Euro 5				
	Brazil (LCV diesel)			Euro 5				Euro 6	
	Brazil (gasoline)			Euro 5				Euro 6	
South Asia	Australia				Euro 4				
	India (New Delhi region)				Euro 4				
	India (other)				Euro 3				
	Indonesia				Euro 4				
	Malaysia				Euro 3				
	Thailand				Euro 4				

3. Material Specifications

The materials used to manufacture the components integrated in the SCR system must principally meet the following requirements:

- **chemical stability**
 - dipolar interaction
 - hydrolysis
- **temperature stability: 80 °C/120 °C**
- **flexibility at low temperatures: –40 °C**
- **purity (DIN 70070)**
- **NH₃ permeation**
- **NH₃ corrosion**

The chemical requirements are derived directly from the SCR system's intended function. The component materials must be resistant against polar and alkaline urea solution (AdBlue®), they may not be subject to hydrolysis and/or be chemically unstable and must also be able to withstand extreme ambient conditions over an extended period of time. Contamination of AdBlue® by any erosion material detached from the conduit material must be avoided, and permeation of ammoniac must be effectively prevented.

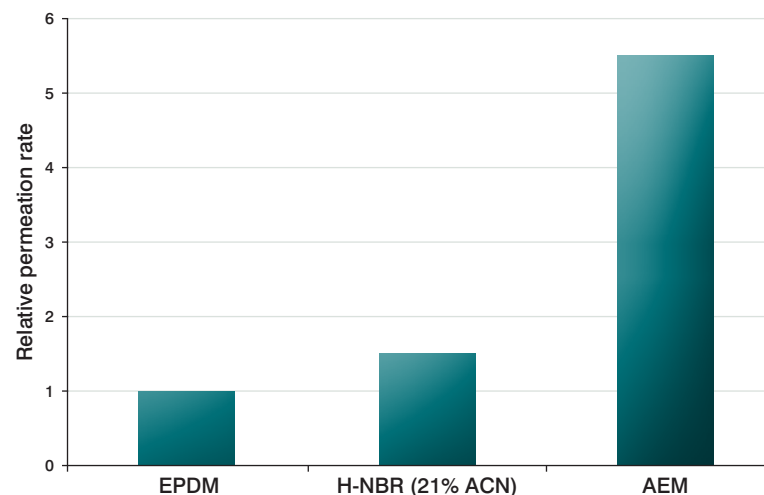
3.1 Elastomers/Amorphous Materials

Dipolar and steric interaction must be taken into consideration when selecting the material for SCR hose conduits, gaskets or membranes. A rule for dipolar interaction is that polar substances are soluble in polar solvents and the non-polar ones in non-polar solvents. Owing to the high dipole moment of the aqueous urea solution, strictly

speaking only non-polar substances consisting of pure hydrocarbon chains such as the elastomers EPDM or butyl rubber (IIR) or cross-linked thermoplastic elastomer (TPV) made of EPDM and/or butyl rubber with proper thermoplastics are suited as hard phase. Weakly polar rubbers such as hydrogenated acrylonitrile-butadiene rubber (H-NBR) with low acrylonitrile (ACN) content and TPE-S, e.g. block copolymers made of styrole and butadiene units are sufficiently/adequately resistant against permanent contact with urea solution.

In selecting materials, particular attention must be paid to the issue of ammoniac permeability specifically in the light of dipolar as well as steric and structural interaction. Several EPDM as well as butyl rubber types feature high molecular weights, dense packings and as a consequence favorable permeation rates.

Chart. 2: Total Permeation of Elastomeric Conduit Materials (AdBlue®)



3.2 Thermoplastics

In the SCR system, plastics are used for a multitude of components and assembly groups such as storage tank, conveyor features, plugs and connectors, filters, valves, fastening elements or (heated) tube conduits. While polyolefins such as HDPE or polypropylene are an option for tanks and casings, materials such as polyoxymethylene (POM) or in particular polyamides are suited for many other components in the conduit system. Long-chained polyamides such as PA 12 are used in a wide variety of applications in automotive conduit engineering and owing to their outstanding properties are suited for almost any purpose. However, in aqueous media, these polyamides at higher temperatures are hydrolytic, i.e. the polymeric chain is broken down by nucleophilic attack and the molecular structure is degraded.

Product Performance and Data Sheet

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Veritas Blue Liner®

Product: SCR Tube

Technical Performance

Dimensions [mm]	Burst pressure	Operating Pressure
25.0 x 2.0 mm	>7 MPa	0 - 2 bar
16 x 1.25 mm	>7 MPa	0 - 2 bar
10 x 1 mm	>7 MPa	0 - 2 bar
8 x 1 mm	>7 MPa	0 - 2 bar

Temperatures:

Service:	80°C
Peak:	120°C
Cold Impact:	-40°C

Conductivity:

Medium: AdBlue urea solution

Features

Issue:	1	2	3	4	5	6	7
Date:	29.07.99						

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Fig. 3: Product Data Sheet

Next to long-term chemical stability, another important aspect is to assure minimum diffusion of ammoniac through conduit walls. In fuel supply lines, PA 12 as well as THV (fluor thermoplastic) display low permeation rates, which is why they have established themselves on the market. However, as relates to ammoniac diffusion, they both fall back considerably as compared to the Veritas Blue Liner®. This Blue Liner® built on the basis of special TPVs owing to its non-polar character features distinctly lower permeation rates than the semi-crystalline variants. The characteristics of suitable engineering design materials for a variety of components and assembly groups of the SCR system are contrasted with each other in chart 3. Owing to its outstanding stress cracking resistance and low-temperature impact strength, fuel tank cells as well as pump casings are preferably made of HDPE – in spite of the relatively inferior mechanical characteristics. Polypropylene and polyoxymethylene are suited for a variety of applications and components and have a favorable price/benefit ratio. Polyamides such as PA 12, PA 6 or PA 66 are recommendable for use only if there are no high demands on chemical stability or permeability.

Tab. 3: Characteristics of Diverse Thermoplastic Materials

	PA	POM	PP	HDPE
Chemical resistance (Ad Blue®, NH ₃)	+-	+	+	+
Permeation	+-	+	+	+
Low-temperature impact strength	+	+	+-	+
Stress cracking resistance	+	+	+-	+
Price	+-	+-	+	+

Fulfillment of requirements: + positive – negative +- neutral

4. Functional Structure of SCR Conduit Systems

The SCR conduit system usually consists of a filling and a venting tract. Both tracts not only differ in terms of their functions, but also in their dimensions and the installed components. The filler neck consists essentially of a filling head, a tube or hose and a connector joining the conduit to the storage tank. A spit-back valve is installed either in the hose or tank. The vent conduit is composed of at least one ventilation valve, which as an alternative may also be installed in the tank, a tube and also a connector joining the conduit to the storage tank.

4.1 Filler Conduit

The process of refueling AdBlue® is defined by the interaction between all used components. Switching off the pump nozzle during the refueling process prior to reaching the required filling volume (»premature shut-off«) must just as much be avoided as liquid splashing from the filler head owing to excessive internal pressure (spit-back).

The interior diameter of the filler conduit must be adequately dimensioned to assure the required flow rate is achieved in the filling process. This flow rate is conditional upon the diverse filling methods. While AdBlue® fueling with canisters or so-called Kruse bottle has no major effects, filling with pump nozzle requires precise monitoring of the flow rate owing to the diverse pump nozzle models in use. Focus is currently on achieving a maximum filling speed of 40l/min as is standard rate for filling trucks, but filling operations at lower feed rates must also be taken into consideration.

4.1.1 Filling Head

The filling head of an SCR system has a variety of functions. There are filling heads for AdBlue® fueling from the outside, which enable the driver to autonomously replenish the AdBlue® storage tank with a pump nozzle, as well as other filling head variants for internal AdBlue® fueling, for example in the car trunk. However, these are suitable only for refilling with canisters or bottles. Refilling from the outside is the prevailing method.

Another factor to be considered in designing the filling head is venting. The storage-tank air displaced by the incoming AdBlue® can either be conducted through the vent line to the filling head or can be directly released to the outside, for example to the wheel case.

The filling head components as well as its major functions are explained in the following text.



Fig. 4: Filling Head



Filling Head Port

The interior diameter of the filling head port must be adapted to accommodate the diverse pump nozzles used to dispense AdBlue®. The outside diameter usually features an exterior thread suited both for screwing on an adapter for canister replenishment and for screwing on an AdBlue® bottle (e.g. Kruse bottle). Those systems passing on to the environment the air displaced during the filling process usually have an internal contour with grooves allowing the emissive air to escape.

Magnet

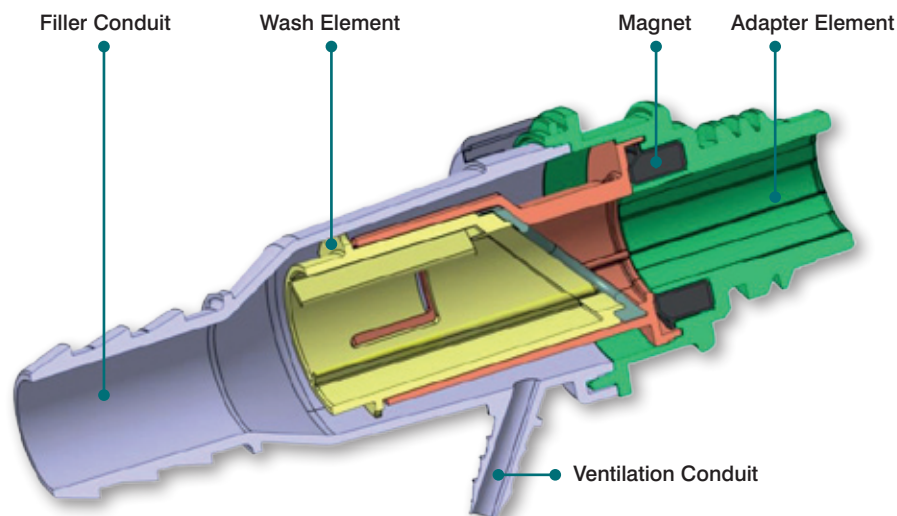
The front section of the filling head features a magnet which is designated to trigger the opening mechanism in the pump nozzle. The intent is to prevent operators from refilling the wrong liquid and to avoid any premature activation of the pump nozzle. The pumping process can be triggered only after the pump nozzle is in its correct position. 80% of the pump nozzles in use across Europe have magnet-triggered release mechanisms, while most of the pump nozzles used in the USA can also be activated without magnet.

Interior Adapter Element in Filler Head

The filler head in numerous applications will feature an adapter element into which the pump nozzle tip is inserted. This adapter element is designated to accommodate manufacturers' various designs of pump nozzles to assure that liquid streams particular to these various designs will not clog the filler neck thereby triggering premature pump nozzle shut-off. Another purpose of this adapter element is to separate the AdBlue® streaming in from the escaping air. It prevents the AdBlue® from being caught in the escaping air and discharging from the filler head port towards the individual filling the tank.

A wash element designated to prevent spit-back of AdBlue® during the refilling process is located in the lower section of the adapter element facing the filler neck. Fin structures in the adapter element stabilize the direction of flow and provide centering aid and limit stop for the pump nozzle. This limit stop is important for holding the pump nozzle in the proper position, an essential condition for activating the magnet's triggering function.

Fig. 5: Filling Head



Filler Head Casing (upper and lower part)

The filler head casing is frequently designed as two or three-part assembly unit to be able to integrate all elements stated above. The casing is also designed to allow attachment of the filler head to the car body, which may be accomplished either by direct fastening or with an additional bracket. The type of attachment chosen depends essentially on the available installation space and the sequence of assembly.

The specified filler head size (volume) should be adequately dimensioned to accommodate spit-back and fill-to-max quantities. The area joining the filler head and the filler neck must be designed in accordance with rheological considerations to avoid any backlog in the filling process.

4.1.2 Tube Component

The need for a relatively large interior diameter for the tube or hose conduit frequently causes problems with conduit routing. Collisions are almost inevitable, as there is usually only little installation space available and small bending radii cannot be accomplished with large conduit diameters. On the other side, ease of handling and conduit flexibility in assembly are high-priority requirements in particular for uncomplicated installation at car assembly plants. To achieve this flexibility, the conduits in some applications are equipped with additional components such as corrugated pipes or hoses. In particular the connection to the storage tank is frequently fitted with a particularly flexible element, on one side in order to assure proper connection of the filling conduit to the AdBlue® tank in the vehicle, on the other to compensate for installation and manufacturing tolerances of the diverse component parts. Furthermore, in the event of an accident leading to car-body deformation, separation of the filling conduit from the storage tank may to some extent be prevented.

4.1.3 Spit-back Valve

After the refilling process has been completed, the tank might discharge excessive interior pressure through the filling tube. Flap valves also called spit-back valves are installed to prevent any liquid from spilling from the tube. This spit-back valve consists of a spring-mounted flap which closes the diameter of the filling tube to prevent any spit-back.



The design of this flap and its sealing gasket must prevent any AdBlue® from accumulating at the flap, where it might freeze. This is important to assure that the flap is operable at all times

Fig. 6: Spit-back Valve



Fig. 7: Open Spit-back Valve



4.1.4 Interface between Filling Conduit and Storage Tank

Simple, convenient, and favorably-priced connections between filling conduit and tank are usually made with quick connectors [QC] preassembled to the filling conduit. If the filling conduit is provided in form of a plastic tube, the QC is punched into the tube with a fir-tree profile. If it is a hose, the quick connector will feature a matching adapter. After the quick connector has been inserted into the hose, it will be locked in place with a clamp or a spring-band clip.

4.2 Vent Line

The purpose of the vent line is to release to the ambient air all the excess pressure arising in the storage tank during the filling process. The vent line is directly connected to the storage tank with a ventilation valve and either interfaces directly with the filling head, which conveys the air in the tank displaced by the filling procedure past the pump nozzle, or has an open end secured with a tight-mesh sieve.

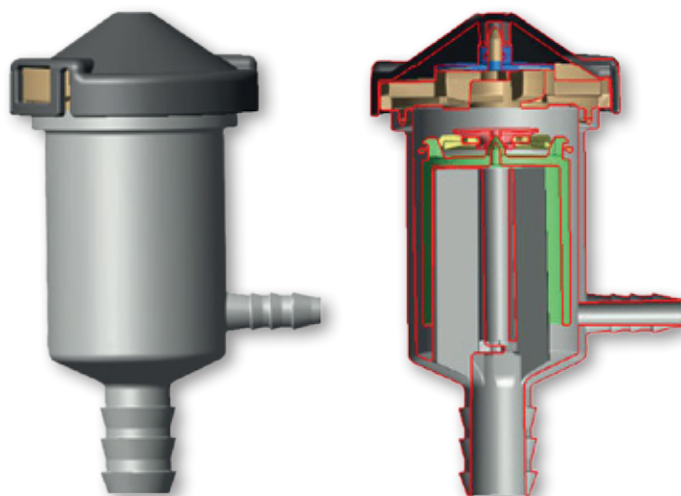
The interior diameter of the vent line is distinctly smaller than the diameter of the filling conduit, however, in order to maintain the required filling rate of 40 l/min, the vent line must rapidly discharge the escaping air, which is why the diameter on the other side may not be too small.

4.2.1 Vent Valve

Quantity, position and type of valves depends strongly upon the design of the entire SCR System. In a standard passenger car, the filler head port is usually found at the highest-possible position in the wheel housing. As a consequence, the ventilation line port is lower than the filler head and liquid might escape. The float valve is installed to prevent exactly this from occurring. A float valve will rise upwards to close the discharge port of the ventilation line.

The advantage of this system is that the air outlet port is positioned behind the car-body panels and that operators will not experience any unpleasant odors. It is essential that float valves must have minimum surface contact to prevent them from freezing. The valve's function must be assured at all driving angles, in particular in SUVs, and the valve must be designed to be elastic and reliable even at -40°C .

Fig. 8: Vent Valve



Another strategy to keep the liquid rising in the ventilation line from escaping is to install a vent surge tank with sufficient capacity to accommodate the liquid volume and to position it between filler head and storage tank. However, an essential requirement here is that there is sufficient installation space available.

Standard Driving Operations

In standard driving operations, a motor vehicle will consume approx. 1 l AdBlue® per 1,000 kms (reference rate). Tank ventilation through vent valves and/or diaphragm must be provided here to allow the AdBlue® consumed in normal driving operations to be replaced by air. An open system cannot be installed owing to the risk of crystallization. (see fig. 8).

5. Tests

In the development phase, extensive tests of the SCR system are conducted to verify the function of all components throughout the entire life cycle. Service life tests simulate the life cycle of complete component groups in time-lapse mode. The requirements are based on legal provisions and customer specifications (company standards and customer requirements sheets). The loads usually applied in varying combinations are temperature variation, pressure fluctuations, and vibration stimulation.

5.1 Veritas AG Test Facilities

Tempering Tests / Long-term Soaking

- 9 tempering cabinets of various sizes available
- effective temperature range between -80°C and +180°C

Excess Pressure / Negative Pressure

- pulsation unit for long-term tests
- optional combination with tempering cabinets

Burst Pressure

- burst pressure test installation for proving diverse materials and temperatures

Vibration Tests

- 3 shaker test benches
- equipped for endurance tests

Multi-axle Excitation

- Hexapod test bench for motion simulation



Fig. 9: Tempering cabinet



Fig. 10: Fueling station



Fig. 11: Slosh Tester endurance test

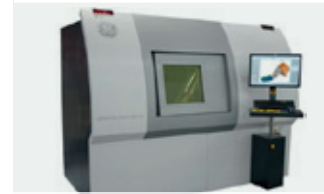


Fig. 12: CT-unit

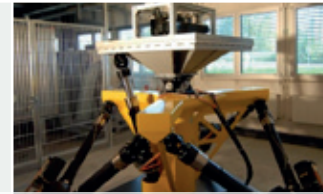


Fig. 13: Driving profile simulation on Hexapod



Fig. 14: Vibration test on shaker

Fueling

- 2 fueling stations for examining fueling conduct
- facilities for testing all components (spit-back, valve functions,...) also in extreme temperature environment

Slosh

- slosh test bench
- velocity and retardation may be adjusted to meet requirements; integrated drive for endurance tests

Dimensional Inspection

- several measuring devices with scanners and/or tactile measuring feature

Material Tests

- Veritas AG is capable of conducting all material analyses (mechanical characteristics and analytics)

6. A look ahead

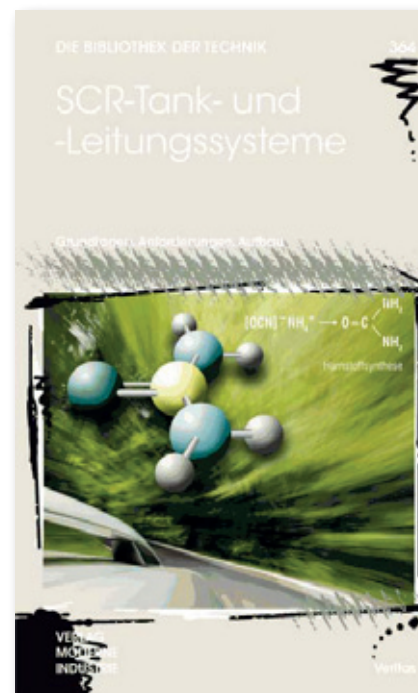
The requirements on environmental protection lead to consistently stricter legislature, which – in addition to reduction of CO₂ emissions and thus reduction of fuel consumption itself – is designed to decrease the emissions of any pollutants whatsoever. This also includes particulate matter and nitrogen oxides (NO_x). The latter may be reduced in conventional combustion engines for example by installing SCR systems.

Contemporary passenger-car propulsion is almost entirely based on combustion engines. Even though in the past years there has been in fact quite some progress made as relates to the development of alternative propulsion systems such as hybrid concepts, battery-operated electric power trains, fuel cells or hydrogen-powered engines – economical, comfortable (range!) and thus marketable solutions will not be available for a number of years to come. Even state-of-the-art hybrid cars in the foreseeable future will not be able to travel without combustion chambers using oil-based fuel.

The important short and mid-term objectives for contemporary SCR systems are installation not only in diesel engines but in gasoline engines as well as simplification of SCR system in order to reduce costs and easier handling of reducing agents. Perhaps the aqueous urea solution currently in use might at some later date be replaced by solid-material products. However, it will certainly be a long time before that is in any way feasible, as handling such solid material is still a major technical challenge on engineers.

In conjunction with an exhaust gas recirculation system (EGR), which decreases temperatures already in the combustion chamber and thereby reduces the formation of nitrogen oxides, the SCR system is the first-line approach to continue putting environmentally compatible cars with combustion engines on the market in the future as well.

Further Reading



Also available in english language
from May 2016

SCR Tank and Conduit Systems Fundamentals, Requirements, Structure

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Veritas - always striving to find innovative solutions for protecting the environment, meeting legal requirements, and further improving automotive functions – all over the world.