

Diesel Emission Control Systems

Legislation

Since the first exhaust emission legislation for petrol engines came into force in the mid-1960s in California, the permissible limits for a range of pollutants have been further and further reduced. In the meantime, all industrial nations have introduced exhaust emission legislation that defines the emission limits for petrol and diesel engines as well as the test methods.

Essentially, the following exhaust emission legislation applies:

- CARB legislation (California Air Resources Board), California
- EPA legislation (Environmental Protection Agency), USA
- EU legislation (European Union) and corresponding ECE regulations (UN Economic Commission for Europe), Europe
- Japan legislation.

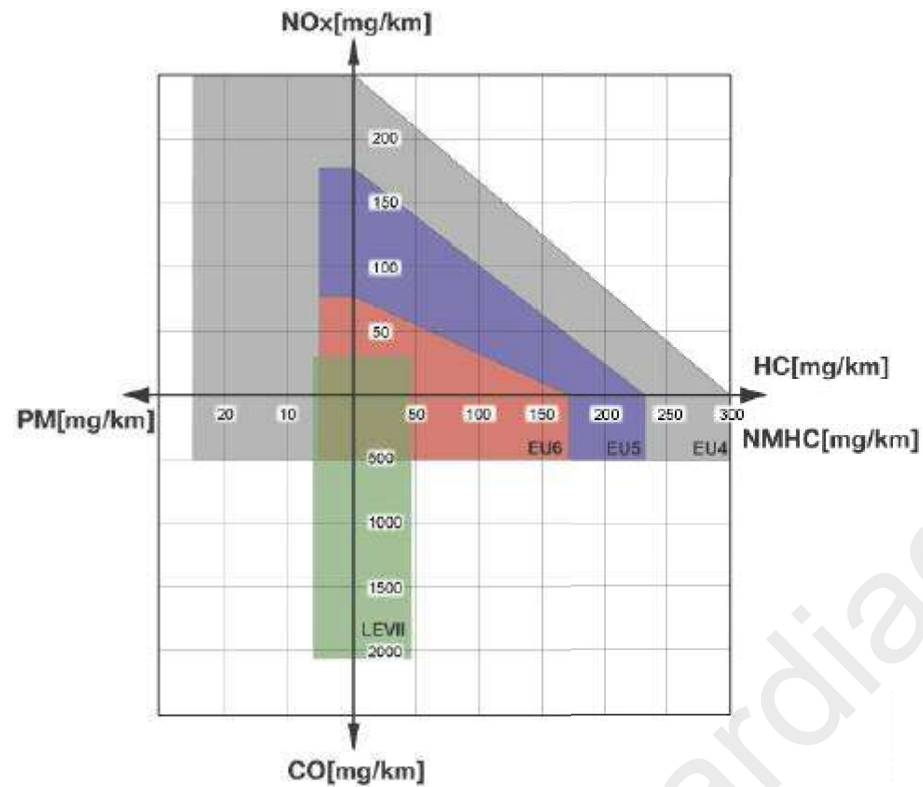
This legislation has led to the development of different requirements with regard to the limitation of various components in the exhaust gas. Essentially, the following exhaust gas constituents are evaluated:

- Carbon monoxide (CO)
- Nitrogen oxides (NO_x)
- Hydrocarbons (HC)
- Particulates (PM)

It can generally be said that traditionally more emphasis is placed on low nitrogen oxide emissions in US legislation while in Europe the focus tends to be more on carbon monoxide. The following graphic compares the standard applicable to BMW diesel vehicles with the current standards in Europe. A direct comparison, however, is not possible as different measuring cycles are used and different values are measured for hydrocarbons.

Although European and US standards cannot be compared 1:1 it is clear that requirements relating to nitrogen oxide emissions are considerably more demanding in the US market. Diesel engines generally have higher nitrogen oxide emission levels than petrol engines as diesel engines are normally operated with excess air. For this reason, the challenge of achieving approval in all 50 states of the USA had to be met with a series of new technological developments.

Comparison of Exhaust Emission Legislation



Standard	Valid from	CO [mg/km]	NO _x [mg/km]	HC+NO _x * [mg/km]	NMHC ** [mg/km]	PM [mg/km]
EURO 4	1-1-05	500	250	300	-	25
EURO 5	9-1-09	500	180	230	-	5
EURO 6	9-1-14	500	80	170	-	5
LEV II	MY 2005	2110	31	-	47	6

* In Europe, the sum of nitrogen oxide and hydrocarbons is evaluated, i.e. the higher the HC.

** In the USA, only the methane-free hydrocarbons are evaluated, i.e. all hydrocarbons with no methane.

Exhaust Gas Recirculation

The recycling of exhaust gases is one of the methods used to reduce NO_x in a diesel engine. By introducing exhaust gas into the intake stream, the amount of oxygen in the combustion chamber is reduced which results in lower combustion chamber temperatures.

The EGR systems differ between the E70 and the E90. Both vehicles use the “high-pressure EGR”, but the E70 uses an additional “low-pressure EGR” system. The low pressure EGR system is required in the E70 due to its additional weight and higher operational loads (i.e. towing etc.).

Low Pressure EGR

The known EGR system has been expanded by the low pressure EGR on the E70. This system offers advantages particularly at high loads and engine speeds. This is why it is used in the heavier E70 as it is often driven in the higher load ranges.

The advantage is based on the fact that a higher total mass of exhaust gas can be recirculated. This is made possible for two reasons:

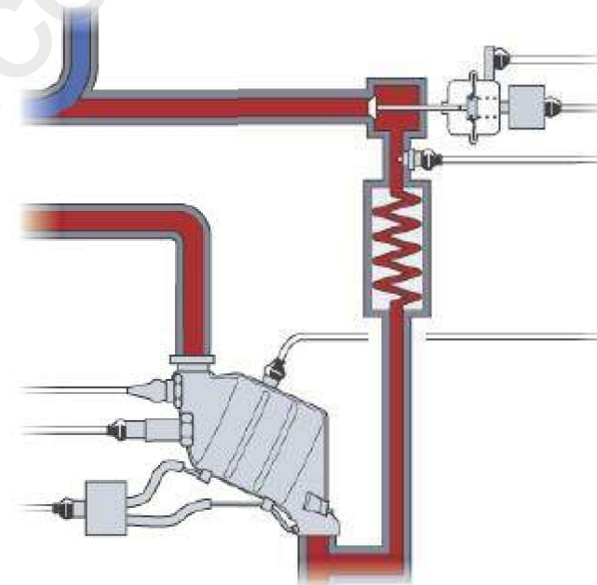
- Lower exhaust gas temperature - The exhaust gas for the low pressure EGR is tapped off at a point where a lower temperature prevails than in the high pressure EGR. Consequently, the exhaust gas has a higher density thus enabling a higher mass.

In addition, the exhaust gas is added to the fresh intake air before the exhaust turbocharger, i.e. before the intercooler, where it is further cooled. The lower temperature of the total gas enables a higher EGR rate without raising the temperature in the combustion chamber.

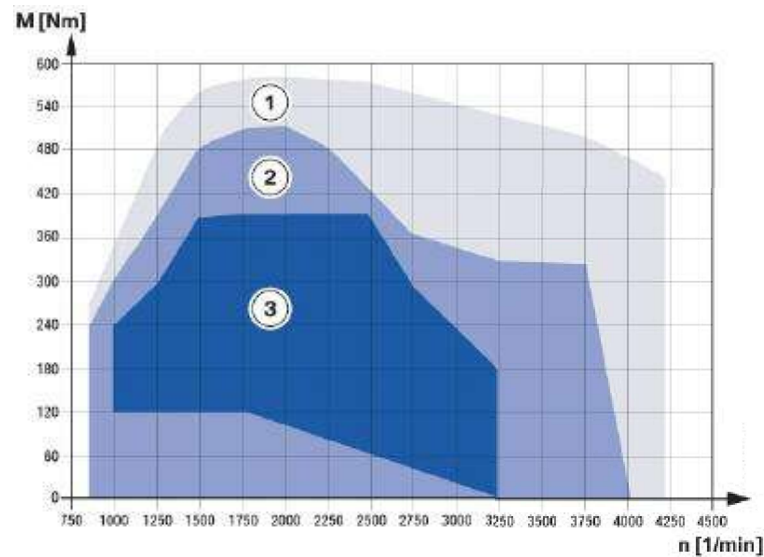
- Recirculation before the exhaust turbocharger - Unlike in the high pressure EGR where the exhaust gas is fed to the charge air already compressed, in this system the exhaust gas is added to the intake air before the exhaust turbocharger. A lower pressure prevails in this area under all operating conditions.

This makes it possible to recirculate a large volume of exhaust gas even at higher engine speed and load whereas this is limited by the boost pressure in the high pressure EGR.

Low pressure EGR system



The following graphic shows the control of the EGR system with low pressure EGR:



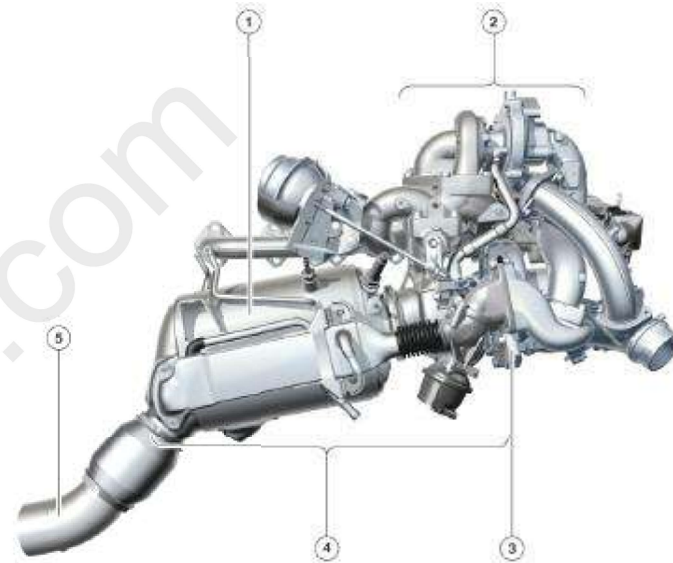
Index	Explanation	Index	Explanation
1	No EGR	3	High and low pressure EGR are active
2	Only high pressure EGR is active		

As already mentioned, the low pressure EGR has the greatest advantage at higher loads and is therefore activated, as a function of the characteristic map, only in this operating mode.

The low pressure EGR, however, is never active on its own but rather always operates together with the high pressure EGR.

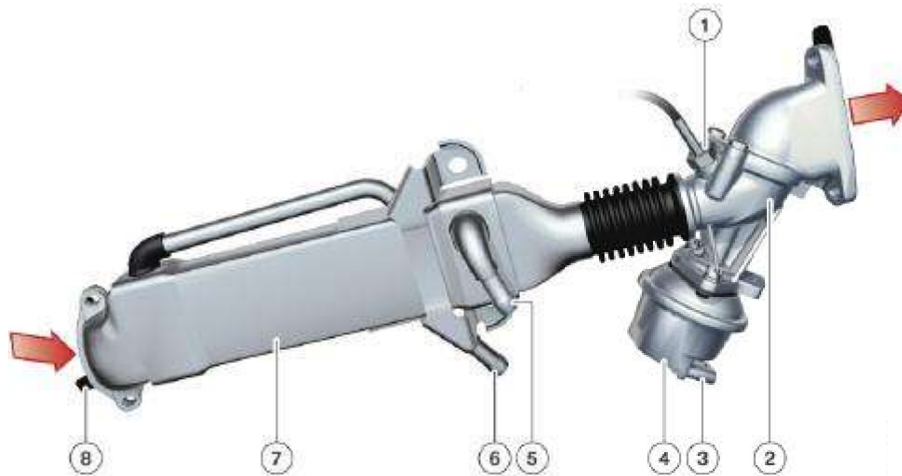
Added to this, it is only activated at a coolant temperature of more than 55°C. The low pressure EGR valve is closed as from a certain load level so that only the high pressure EGR valve is active again. This means the EGR rate is continuously reduced.

The low pressure EGR system is located on the right-hand side on the engine directly next to the diesel particulate filter and the low pressure stage of the turbo assembly. The exhaust gas is branched off directly after the diesel particulate filter and fed to the intake air before the compressor for the low pressure stage.



Index	Explanation	Index	Explanation
1	DPF	4	Low pressure EGR
2	Turbocharger assembly	5	Exhaust system
3	Exhaust turbocharger, low pressure stage		

The following graphic shows the components of the low pressure EGR:

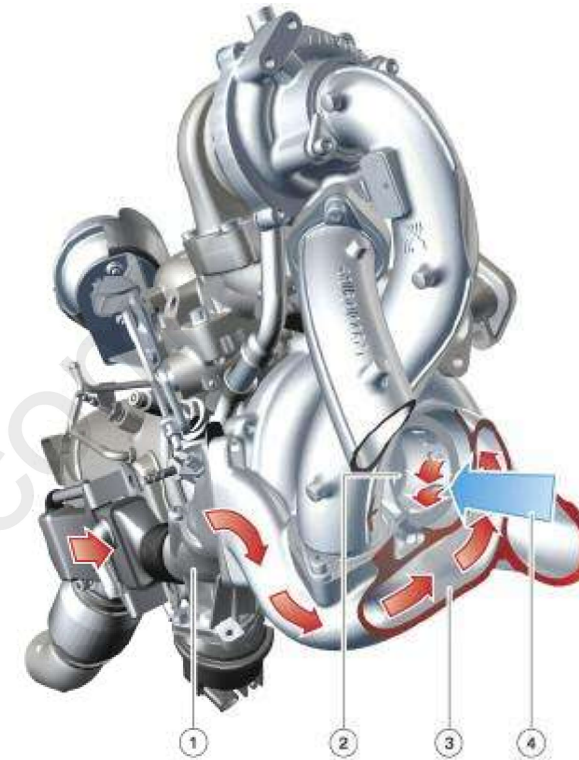


Index	Explanation	Index	Explanation
1	Temperature sensor - LP EGR	5	Coolant infeed
2	LP-EGR valve	6	Coolant return
3	Connection for positional feedback	7	LP-EGR cooler
4	Vacuum unit for LP-EGR valve	8	Sheet metal gasket with filter

There is a fine meshed metal screen filter located at the exhaust gas inlet from the diesel particulate filter to the low pressure EGR system. The purpose of this filter is to ensure that no particles of the coating particularly in a new diesel particulate filter can enter the low pressure EGR system.

Such particles would adversely affect the compressor blades of the exhaust turbocharger.

The metal screen filter must be installed when fitting the low pressure EGR cooler to the diesel particulate filter otherwise there is a risk of the turbocharger being damaged.



Index	Explanation	Index	Explanation
1	Cleaned blow-by gas	3	Intake manifold
2	Ventilation, naturally aspirated operation	4	Clean-air pipe

■ Exhaust Turbocharger

The US engine is equipped with the same variable twin turbo as the European version, however, the turbo assembly is modified due to the low pressure EGR.

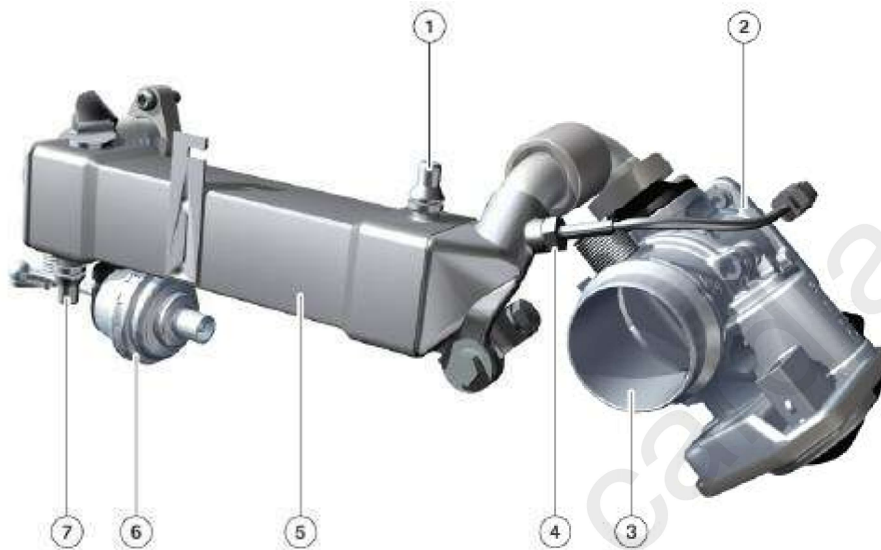
On the one hand, the inlet for the low pressure EGR is located on the compressor housing for the low pressure stage. On the other hand, the compressor wheels are nickel-coated to protect them from the exhaust gas.

High Pressure EGR

The exhaust gas recirculation known to date is referred to here as the high pressure EGR in order to differentiate it from the low pressure EGR.

Compared to the European version, the high pressure EGR is equipped with the following special features:

- Electric EGR valve with positional feedback
- Temperature sensor before high pressure EGR valve
- EGR cooler with bypass.



Index	Explanation	Index	Explanation
1	Coolant inlet	5	High pressure EGR cooler
2	High pressure EGR valve	6	Vacuum unit of bypass valve for HP-EGR cooler
3	Throttle valve	7	Coolant return
4	Temperature sensor, HP-EGR		

The electric actuating system of the EGR valve enables exact metering of the recirculated exhaust gas quantity. In addition, this quantity is no longer calculated based solely on the signals from the hot-film air mass meter and oxygen sensor but the following signals are also used:

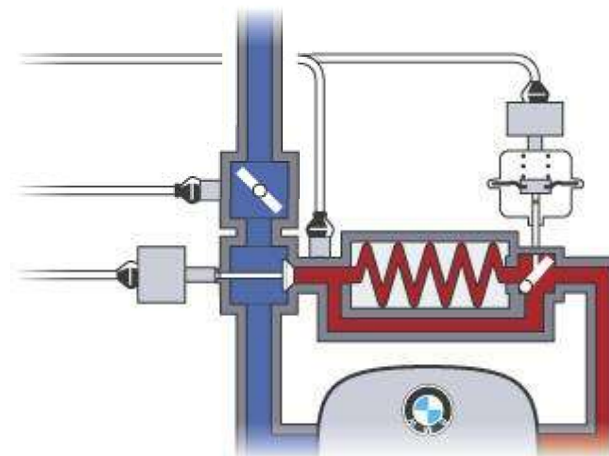
- Travel of high pressure EGR valve
- Temperature before high pressure EGR valve
- Pressure difference between exhaust gas pressure in the exhaust manifold and boost pressure in the intake manifold.

This enables even more exact control of the EGR rate.

The EGR cooler serves the purpose of increasing the efficiency of the EGR system. However, reaching the operating temperature as fast as possible has priority at low engine temperatures.

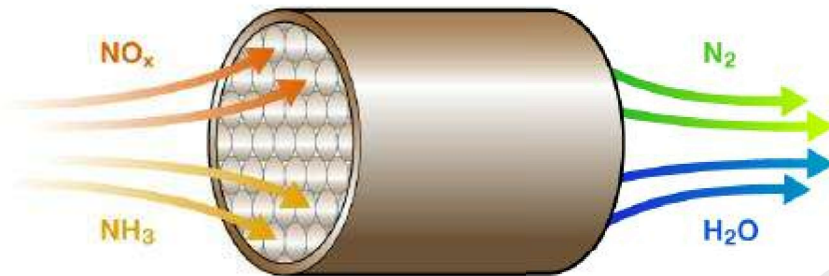
In this case, the EGR cooler can be bypassed in order to heat up the combustion chamber faster. For this purpose, there is a bypass that diverts the flow of the exhaust around the EGR cooler.

This bypass is actuated by a flap which, in turn, is operated by a vacuum unit. The bypass is either only in the "Open" or "Closed" position.



Selective Catalytic Reduction

In order to comply with stringent EPA guidelines, the new Selective Catalytic Reduction (SCR) system is installed in the new diesel vehicles from BMW. The M57D30T2 engine complies with the EPA Tier 2, Bin 5 requirements. This allows the new diesel vehicles to be sold in all 50 states.



The SCR system is a recently new development in the automotive industry, but this technology has been in use by coal fired power plants for many years.

The term “selective” indicates that the reducing agent prefers to oxidize selectively with the oxygen contained in the nitrogen oxides instead of the oxygen present in the exhaust gas.

The reducing agent is injected into the exhaust system where it is converted to ammonia and carbon dioxide. The resulting ammonia is used within a special catalyst in the exhaust stream.

The resulting reaction converts the unwanted oxides of nitrogen into harmless nitrogen and water.

The preferred reducing agent in an SCR system is ammonia (NH_3). However, ammonia by itself is toxic and would not be practical or safe to carry in the vehicle. So, an alternative would be a safer “carrier” substance which, in this case, is a urea/water compound.

Urea, $(\text{NH}_2)_2\text{CO}$, is commonly used as a fertilizer and is biologically compatible with groundwater and chemically stable for the environment. This allows urea to be used as the reducing agent in the SCR system. The ammonia is then extracted from the urea during an “on-board” chemical reaction which takes place once the urea is injected into the exhaust system.

The official name for the reducing agent is Diesel Exhaust Fluid or DEF. This is the name that will be used in the owner’s manual and in this training material.

See note below:

Important note on DEF

In this training material, there are several terms which are in use for DEF. Some of these terms include reductant, reducing agent or urea/water solution.

The technical name used industry wide is AUS32, which is a urea/water solution of which urea comprises 32.5% of the mixture.

Another term which is used is AdBlue, which is the registered trademark for AUS32. However, there are other producers of AUS32. AdBlue is just one of them.

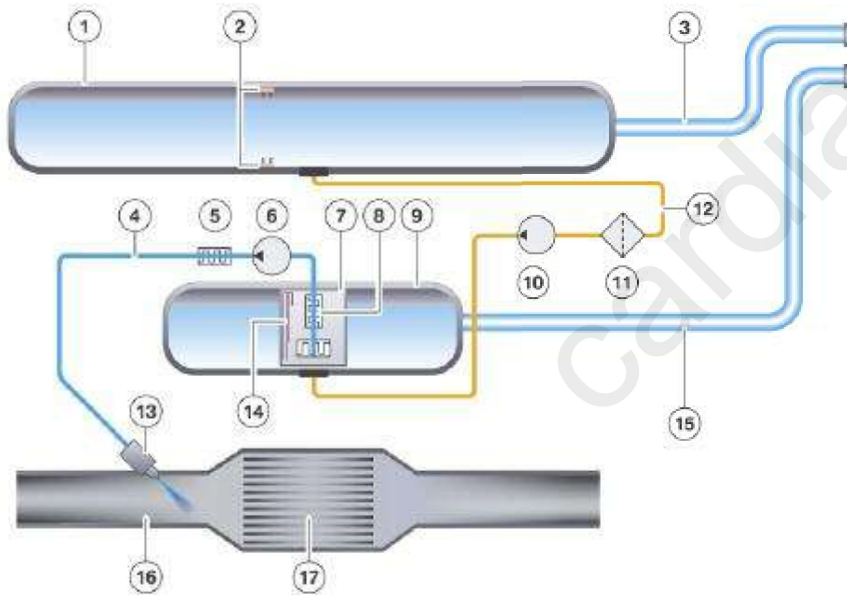
The AdBlue trademark is currently held by the German Association of the Automobile Industry (VDA), who ensure quality standards are maintained in accordance with DIN 70070 specifications.

SCR Overview - Simplified

Selective catalytic reduction is a system for reducing nitrogen oxides (NO_x) in the exhaust gas. For this purpose, a reducing agent (urea/water solution) is injected into exhaust gas downstream of the diesel particulate filter.

The nitrogen oxide reduction reaction then takes place in the SCR catalytic converter. The urea-water solution is carried in two reservoirs in the vehicle. The quantity is measured out such that it is sufficient for one oil change interval.

The following graphic shows a **simplified representation** of the system:



Index	Explanation	Index	Explanation
1	Passive reservoir	10	Transfer pump
2	Level sensors	11	Filter
3	Filler pipe, passive tank	12	Transfer line
4	Metering line	13	Metering module
5	Metering line heater	14	Level sensor
6	Pump	15	Filler pipe, active reservoir
7	Function unit	16	Exhaust system
8	Heater, in active tank	17	SCR catalytic converter
9	Active tank		

The reason for using two reservoirs is that the urea-water solution freezes at a temperature of -11°C (12.2°F). For this reason, the smaller “active” reservoir is heated but the larger passive reservoir is not. In this way, the entire volume of the urea-water solution need not be heated, thus saving energy. The amount in the active tank is sufficient, however, to cover large distances.

The small, heated reservoir is referred to as the active reservoir. A pump conveys the urea-water solution from this reservoir to the metering module. This line is also heated.

The larger, unheated reservoir is the passive reservoir. A transfer pump regularly conveys the urea-water solution from the passive reservoir to the active reservoir.

SCR System Components

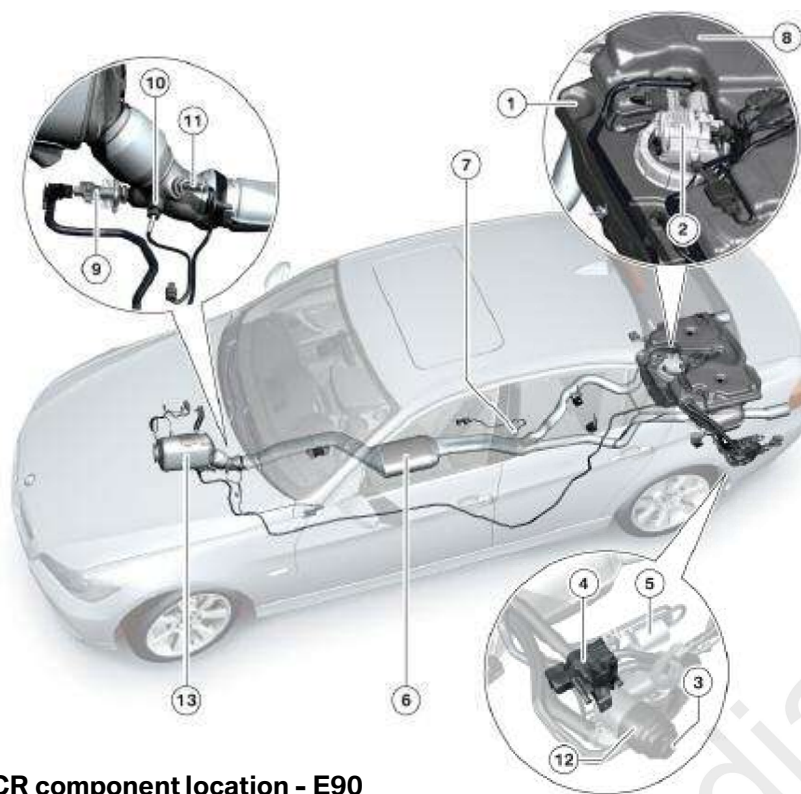


SCR component location - E70

Index	Explanation	Index	Explanation
1	Active tank	8	Passive tank
2	Delivery module	9	Metering module
3	Filler for active tank	10	Exhaust gas temp sensor - post DPF
4	Transfer pump	11	NO _x sensor - pre SCR catalyst
5	Filter	12	Filler neck for passive tank
6	SCR catalyst	13	DOC/DPF
7	NO _x sensor - post SCR catalyst		

■ Component Location - E70

On the E70, the active reservoir, including the delivery unit, is located on the right-hand side directly behind the front bumper panel. The passive reservoir is located on the left in the underbody, approximately under the driver's seat. The transfer unit is installed on the right in the underbody. Both fillers are located in the engine compartment.



SCR component location - E90

■ Component Location - E90

On the E90, both the active reservoir as well as the passive reservoir are located under the luggage compartment floor with the active reservoir being the lowermost of both.

The fillers are located on the left-hand side behind the rear wheel where they are accessible through an opening in the bumper panel. The fillers are arranged in the same way as the reservoirs, i.e. the lower most is the filler for the active reservoir. The transfer unit and the filter are located behind the filler.

Index	Explanation	Index	Explanation
1	Active tank	8	Passive tank
2	Delivery module	9	Metering module
3	Filler for active tank	10	Exhaust gas temp sensor - post DPF
4	Transfer pump	11	NO _x sensor - pre SCR catalyst
5	Filter	12	Filler neck for passive tank
6	SCR catalyst	13	DOC/DPF
7	NO _x sensor - post SCR catalyst		

Passive Reservoir

The passive reservoir is the larger of the two supply reservoirs. The name passive reservoir refers to the fact that it is not heated.

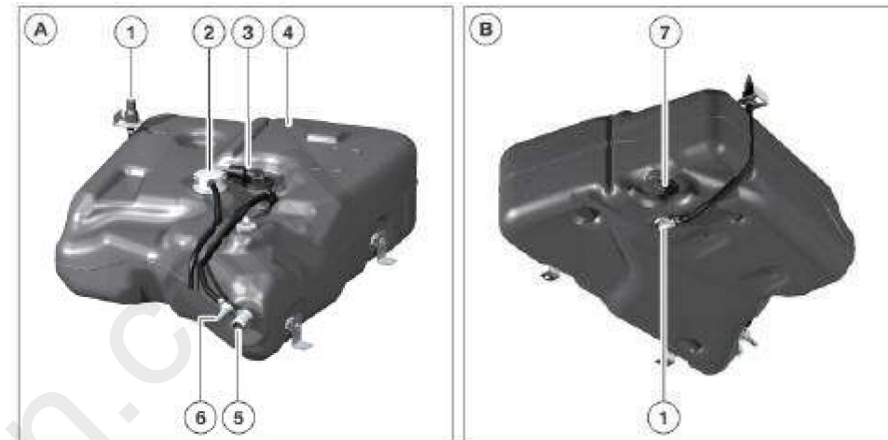
The following components make up the passive reservoir:

- Level sensors (2x)
- Operating vent (2x on E90)
- Filler vent.



Index	Explanation	Index	Explanation
1	Operating vent	5	Fill line connection
2	Filler vent	6	"empty" level sensor
3	"full" level sensor	7	Passive reservoir
4	Operating vent		

The passive reservoir on the E70 is encased in insulation as it is positioned near the front of the exhaust system where the heat transfer to the urea-water solution would be very high.



Index	Explanation	Index	Explanation
1	Connection for transfer line	5	Fill line connection
2	Operating vent	6	Filler vent
3	"full" level sensor	7	"empty" level sensor
4	Passive reservoir		

Vehicle	Volume	Location	Position of filler neck
E70	16.5 l	In underbody, under driver's seat (approximately)	In the engine compartment, left side, under unfiltered air inlet
E90	14.4 l	Under luggage compartment floor	Left side in rear bumper

Level Sensors

There are two level sensors in the passive reservoir. One supplies the "Full" signal and the other the "Empty" signal.

The sensors make use of the conductivity of the urea-water solution. When these contacts are wetted with urea-water solution the circuit is closed and current can flow, thus enabling a sensor signal.

The two level sensors send their signal to an evaluator. This evaluator filters the signals and recognizes, for example, sloshing of the urea-water solution and transfers a corresponding level signal to the digital diesel electronics.

The "Full" level sensor is located at the top of the passive reservoir. Both contacts are wetted when the passive reservoir is completely filled and the sensor sends the "Full" signal.

The "Empty" level sensor is located at the bottom end of the passive reservoir. The reservoir is considered to be "not empty" for as long as the sensor is covered by urea-water solution. The evaluator detects that the passive reservoir is empty when no sensor signal is received.

■ Venting

The passive reservoir is equipped with one operating vent (2 in the E90) and one filler vent. The operating vent is directed into the atmosphere. A so-called sintered filter tablet ensures that no impurities can enter the reservoir via the operating vent. This sintered tablet consists of a porous material and serves as a filter that allows particles only up to a certain size to pass through.

The filler vent is directed into the filler pipe and therefore no filter is required.



Transfer Unit

The transfer unit pumps the urea-water solution from the passive reservoir to the active reservoir. There is a screen filter in the inlet port of the pump.

This pump is designed as a diaphragm pump. It operates in a similar way to a piston pump but the pump element is separated from the medium by a diaphragm. This means there are no problems regarding corrosion.



Index	Explanation
1	Connection for transfer line to passive reservoir (inlet)
2	Electrical connection for pump motor
3	Connection for transfer line to active reservoir (outlet)

Active Reservoir

The active reservoir is the smaller of the two reservoirs and its name refers to the fact that it is heated. In view of its small volume, little energy is required to heat the urea-water solution.



Active reservoir - E90

Index	Explanation	Index	Explanation
1	Active reservoir	4	Filler vent
2	Operating vent	5	Fill line connection
3	Delivery module	6	Connection of transfer line from passive reservoir



Active reservoir - E70

Index	Explanation
1	Fill line connection, active reservoir
2	Delivery module
3	Metering line
4	Filler vent
5	Connection of transfer line from passive reservoir
6	Active reservoir

Vehicle	Volume	Location	Position of filler neck
E70	6.4 l	On front, right side in side panel module between bumper panel and wheel arch	In the engine compartment, on the front right hand side
E90	7.4 l	Behind rear axle differential, directly under the passive reservoir	Left side in rear bumper panel

Function Unit

The so-called function unit is located in the active reservoir. It has the external appearance of a surge chamber and accommodates a heater, filter and a level sensor. The delivery unit is attached to it.

Unlike a surge chamber in the fuel tank, the lower section of the function unit has slots. This chamber creates a smaller volume in the reservoir that scarcely mixes with the urea-water solution outside the chamber.

There is a PTC heating element (positive temperature coefficient) in the base of the chamber that can heat up this smaller volume at a relatively fast rate. The intake line is also heated. In this way, the liquid urea-water solution can be made available for vehicle operation even at the lowest temperatures.



Index	Explanation
1	Operating vent
2	Bowl
3	Level sensor

The heating element in the chamber is connected to the heater for the intake line to form one heating circuit. A power semiconductor supplies the current for this heating circuit. The power semiconductor is controlled by the DDE. The DDE can determine the current that flows across the heating elements and can therefore monitor their operation.

The temperature sensor provides the signal for the heating control system. It is designed as an NTC sensor (negative temperature coefficient). The temperature sensor is integrated at the bottom end of the level sensor.



Index	Explanation	Index	Explanation
1	Level sensor	4	Intake line with heater
2	Heating element	5	Operating vent
3	Filter		

■ Level Sensor

The level sensor in the function unit provides the level value for the entire active reservoir. The level sensor in the active reservoir operates in accordance with the same principle as the level sensors in the passive reservoir. In this case, however, there is only one sensor with several contacts that extend at different levels into the active reservoir.

The sensor makes use of the conductivity of the urea-water solution. A total of four contacts project into the reservoir. When these contacts are wetted with urea-water solution the circuit is closed and current can flow, thus enabling a sensor signal.

Three contacts are responsible for signalling the different levels. The fourth contact is the reference, i.e. the contact via which the electric circuit is closed. This reference contact cannot be seen in the figure as it is located directly behind the "Empty" contact (3).

The level sensor sends its signal to an evaluator. This evaluator filters the signal and recognizes, for example, sloshing of the urea-water solution and transfers a corresponding level signal to the digital diesel electronics.



Index	Explanation
1	"Full contact"
2	Warning contact
3	"Empty contact"

Delivery Unit

The delivery unit is located on the active reservoir at the top end of the function unit. Among other things, the delivery unit comprises the pump that transfers the urea-water solution from the active reservoir to the metering module. The delivery unit is also heated by a PTC element.



Index	Explanation	Index	Explanation
1	Pump motor and heater electrical connection	3	Pressure sensor electrical connection
2	Reversing valve electrical connection	4	Metering line fluid connection

The heating element in the delivery unit is connected to the heater for the metering line to form one heating circuit. A power semiconductor supplies the current for this heating circuit. The power semiconductor is controlled by the DDE. The DDE can determine the current that flows across the heating elements and can therefore monitor their operation.

■ Pump

The pump is a common part with the pump in the transfer unit. While the engine is running, it pumps the urea-water solution from the active reservoir to the metering module. It draws the metering line empty when the engine is turned off.

■ Pressure Sensor

The pressure sensor measures the pressure in the delivery line to the metering module. The value is transferred to the DDE.

■ Reversing Valve

The reversing valve ensures the delivery direction in the metering line can be reversed to empty the metering line while the pump delivers in the same direction. It is designed as a 4/2-way valve interchanges the metering line and intake line to the pump.

The valve is not actuated in intervals and therefore has only two positions. Since power is permanently applied to the valve when it is actuated, the maximum actuation time is limited in order to avoid overheating.

Metering Module and Mixer

The metering module is responsible for injecting the urea-water solution into the exhaust pipe. It features a valve that is similar to the fuel injector in a petrol engine with intake manifold injection.

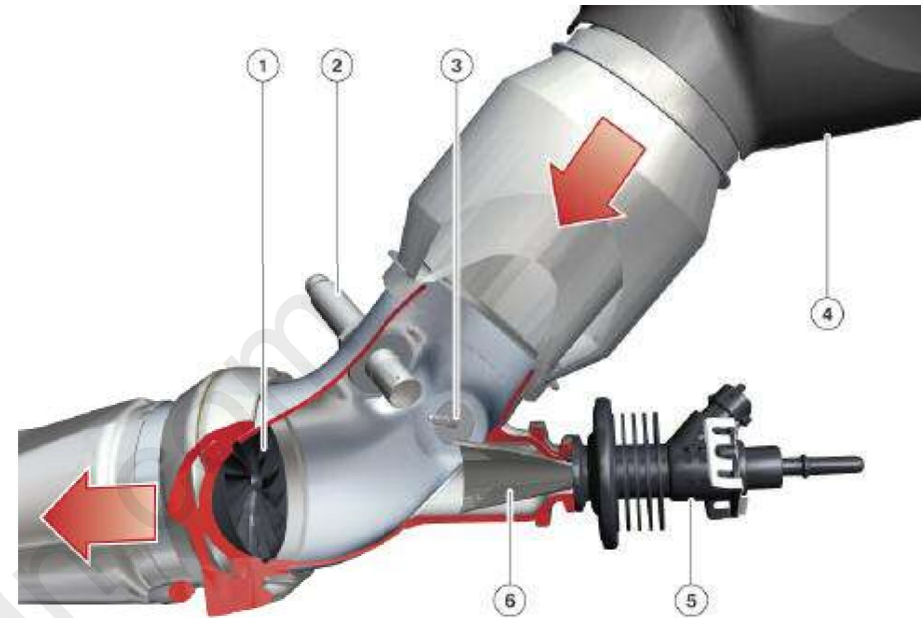


Index	Explanation	Index	Explanation
1	Metering line connection	2	Metering valve connection

Although the metering module does not have a heater, it is still heated by the exhaust system to such an extent that it even requires cooling fins.

The metering module is actuated by a pulse-width modulated (PWM) signal from the DDE such that the pulse duty factor determines the opening duration of the valve.

The metering module is equipped with a tapered insert (6) that prevents urea-water solution residue drying up and clogging the valve. Its shape creates a flow that prevents urea-water solution from collecting on the walls of the exhaust system. Urea deposits on the insert are burnt off as it is heated to very high temperatures by the flow of exhaust gas.



Index	Explanation	Index	Explanation
1	Mixer	4	DPF
2	NO _x sensor - pre SCR catalyst	5	Metering module
3	Exhaust gas temperature sensor after DPF	6	Insert

Mixer

The mixer mounted in the flange connection of the exhaust pipe is located directly behind the metering module in the exhaust system. It swirls the flow of exhaust gas to ensure the urea-water solution is thoroughly mixed with the exhaust gas. This is necessary to ensure the urea converts completely into ammonia.

NO_x Sensors

The nitrogen oxide sensor consists of the actual measuring probe and the corresponding control unit. The control unit communicates via the LoCAN with the engine control unit.



In terms of its operating principle, the nitrogen oxide can be compared with a broadband oxygen sensor. The measuring principle is based on the idea of basing the nitrogen oxide measurement on oxygen measurement.

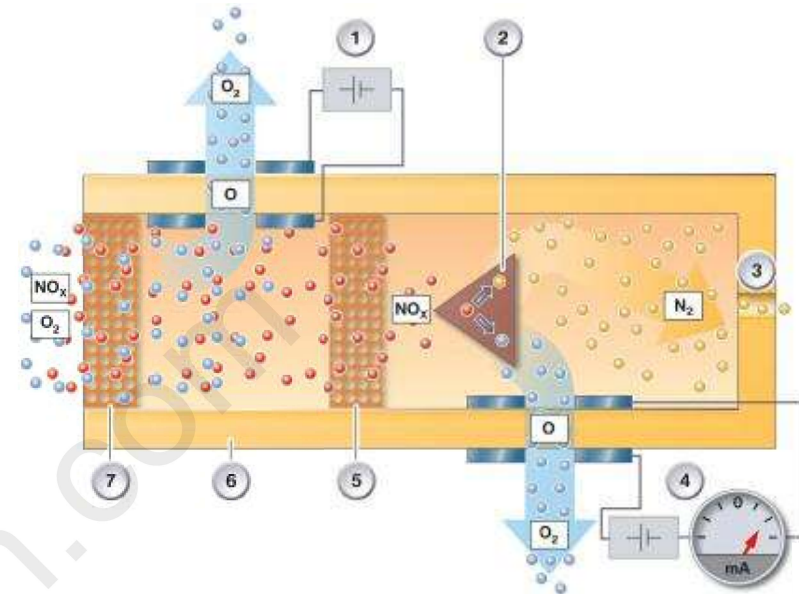
The exhaust gas flows through the NO_x sensor. Here, only oxygen and nitrogen oxides are of interest. In the first chamber, the oxygen is ionized out of this mixture with the aid of the first pump cell and passed through the solid electrolyte.

A lambda signal can be tapped off from the pump current of the first chamber. In this way, the exhaust gas in the NO_x sensor is liberated from free oxygen (not bound to nitrogen).

The remaining nitrogen oxide then passes through the second barrier to reach the second chamber of the sensor. Here, the nitrogen oxide is split by a catalytic element into oxygen and nitrogen.

The oxygen released in this way is again ionized and can then pass through the solid electrolyte. The pump current that occurs during this process makes it possible to deduce the quantity of oxygen and the nitrogen level can be concluded from this quantity.

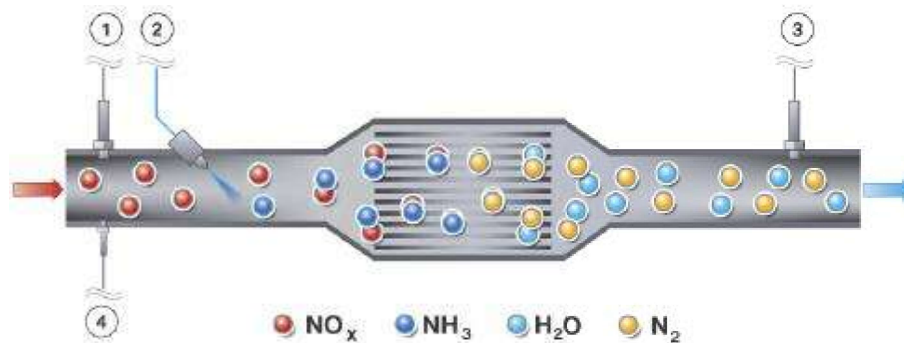
The following graphic shows the functional principle of this measuring system.



Index	Explanation	Index	Explanation
1	Pump flow, 1st chamber	5	Barrier 2
2	Catalytic element	6	Solid electrolyte Zircon dioxide (ZrO ₂)
3	Nitrogen outlet	7	Barrier 1
4	Pump flow 2nd chamber		

Functions of the SCR System

Selective catalytic reduction is currently the most effective system for reducing nitrogen oxides (NO_x). During operation, it achieves an efficiency of almost 100% and approximately 90% over the entire vehicle operating range. The difference is attributed to the time the system requires until it is fully operative after a cold start.



In the SCR catalytic converter, the ammonia reacts with the nitrogen oxides to produce nitrogen (N_2) and water (H_2O).

A further NO_x sensor that monitors this function is located downstream of the SCR catalytic converter.

A temperature sensor in the exhaust pipe after the diesel particulate filter (i.e. before the SCR catalytic converter) and the metering module also influences this function. This is because injection of the urea-water solution only begins at a minimum temperature of 200°C (392°F).

Index	Explanation	Index	Explanation
1	NO_x sensor, pre catalyst	3	NO_x sensor, post catalyst
2	Metering module	4	Temperature sensor after DPF

This system carries a reducing agent, urea-water solution, in the vehicle. The urea-water solution is injected into the exhaust pipe by the metering module upstream of the SCR catalytic converter.

The DDE calculates the quantity that needs to be injected. The nitrogen oxide content in the exhaust gas is determined by the NO_x sensor before the SCR catalytic converter.

Corresponding to this value, the exact quantity of the urea-water solution required to fully reduce the nitrogen oxides is injected. The urea-water solution converts to ammonia in the exhaust pipe.

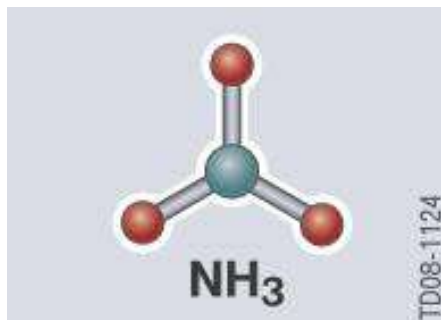
Chemical Reaction

The task of the SCR system is to substantially reduce the nitrogen oxides (NO_x) in the exhaust gas. Nitrogen oxides occur in two different forms:

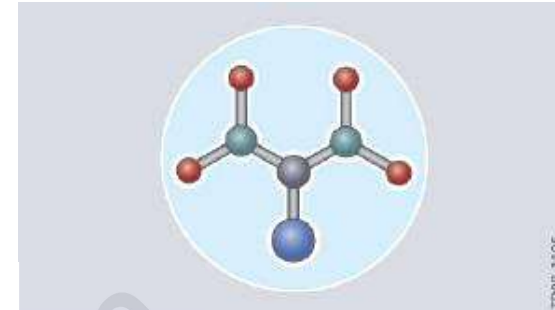
- Nitrogen monoxide (NO)
- Nitrogen dioxide (NO_2).



Ammonia (NH_3) is used for the purpose of reducing the nitrogen oxides in a special catalytic converter. The ammonia is supplied in the form of a urea-water solution.



Urea-water solution

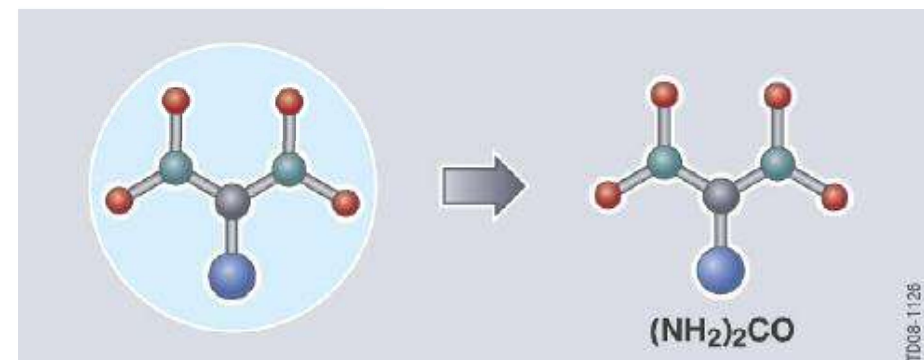


The urea-water solution is injected by the metering system into the exhaust system downstream of the diesel particulate filter. The required quantity must be metered exactly as otherwise nitrogen oxides or ammonia would emerge at the end. The following description of the chemical processes explains why this is the case.

Conversion of the Urea-water Solution

The uniform distribution of the urea-water solution in the exhaust gas and the conversion to ammonia take place in the exhaust pipe upstream of the SCR catalytic converter.

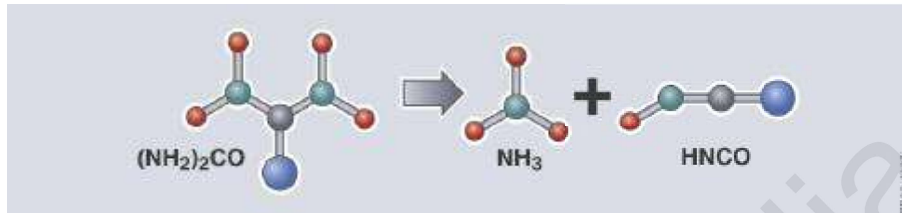
Initially, the urea ($(\text{NH}_2)_2\text{CO}$) dissolved in the urea-water solution is released. The conversion of urea into ammonia takes place in two stages.



Release of Urea from urea-water solution

Thermolysis	
Explanation:	During thermolysis, the urea-water solution is split into two products as a result of heating
Initial Products:	Urea ($(\text{NH}_2)_2\text{CO}$)
Result:	Ammonia (NH_3) Isocyanic acid (HNCO)
Chemical Formulas:	$(\text{NH}_2)_2\text{CO} > \text{NH}_3 + \text{HNCO}$

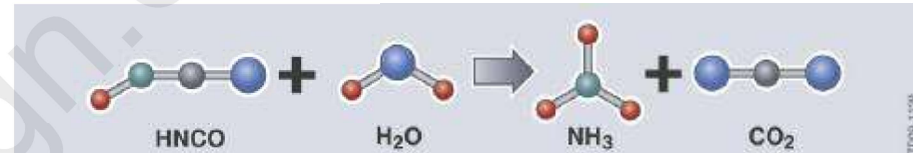
Thermolysis: Urea converts to ammonia and isocyanic acid



This means, only a part of the urea-water solution is converted into ammonia during thermolysis. The remainder, which is in the form of isocyanic acid, is converted in a second step.

Hydrolysis	
Explanation:	The isocyanic acid that was produced during thermolysis is converted into ammonia and carbon dioxide (CO_2), by the addition of water in the hydrolysis process.
Initial Products:	Isocyanic acid (HNCO) Water (H_2O)
Result:	Ammonia (NH_3) Carbon dioxide (CO_2)
Chemical Formulas:	$\text{HNCO} + \text{H}_2\text{O} > \text{NH}_3 + \text{CO}_2$

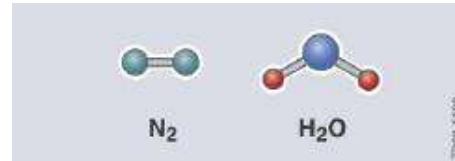
Hydrolysis: Isocyanic acid reacts with water to form ammonia and carbon dioxide



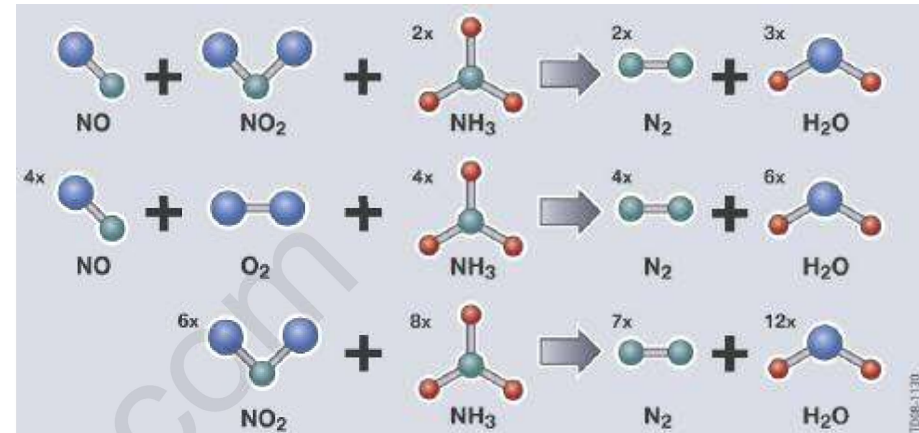
The water required for this purpose is also provided by the urea-water solution. Therefore, following hydrolysis, all the urea is converted into ammonia and carbon dioxide.

NO_x Reduction

Nitrogen oxides are converted into harmless nitrogen and water in the SCR catalytic converter.



Reduction	
Explanation:	The catalytic converter serves as a "docking" mechanism for the ammonia molecules. The nitrogen oxide molecules meet the ammonia molecules and the reaction starts and energy is released. This applies to NO in the same way as to NO ₂ .
Initial Products:	Ammonia (NH ₃) Nitrogen monoxide (NO) Nitrogen dioxide (NO ₂) Oxygen (O ₂)
Result:	Nitrogen (N ₂) Water (H ₂ O)
Chemical Formulas:	$\text{NO} + \text{NO}_2 + 2\text{NH}_3 > 2\text{N}_2 + 3\text{H}_2\text{O}$ $4\text{NO} + \text{O}_2 + 4\text{NH}_3 > 4\text{N}_2 + 6\text{H}_2\text{O}$ $6\text{NO}_2 + 8\text{NH}_3 > 7\text{N}_2 + 12\text{H}_2\text{O}$



NO_x reduction: Nitrogen oxides react with ammonia to form nitrogen and water

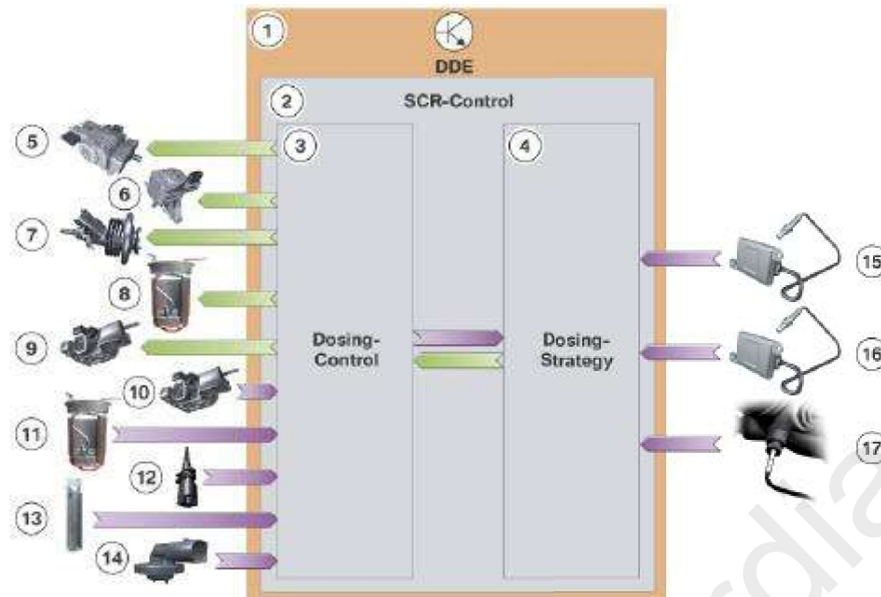
It can be seen that each individual atom has found its place again at the end of the process, i.e. exactly the same elements are on the left as on the right.

This takes place only when the ratio of the urea-water solution to nitrogen oxides is correct. Nitrogen oxides would emerge if too little urea-water solution were injected.

By the same token, ammonia would emerge if too much urea-water solution were injected, resulting in unpleasant odor and possible damage to the environment.

SCR Control

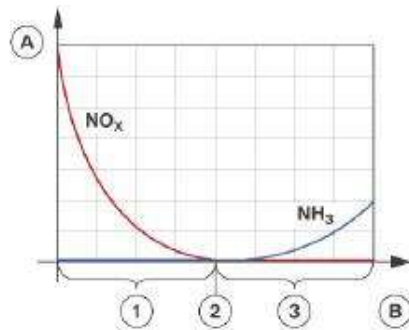
The SCR control is integrated in the digital diesel electronics (DDE).
The SCR control is divided into the metering system control and the metering strategy.



Index	Explanation	Index	Explanation
1	DDE 7.3	10	Pressure sensor
2	SCR control	11	Temperature sensor in active reservoir
3	Metering system control	12	Outside temperature sensor
4	Metering strategy	13	Level sensor in active reservoir
5	Injection pump	14	Level sensor in passive reservoir
6	Transfer pump	15	NO _x sensor - pre SCR catalyst
7	Metering module	16	NO _x sensor - post SCR catalyst
8	Heater	17	Exhaust temperature sensor
9	Reversing valve		

Metering Strategy

The metering strategy is an integral part of the SCR control that calculates how much urea-water solution is to be injected at what time.



Index	Explanation
A	Value from NO _x sensor
B	Injected quantity of urea-water solution
1	Too-little urea-water solution injected
2	Correct quantity of urea-water solution injected
3	Too-much urea-water solution injected

The NO_x sensor, however, measures not only nitrogen oxides but also ammonia but cannot distinguish between them. If too much urea-water solution is injected, although the nitrogen oxides are completely reduced so-called "ammonia slip" occurs, i.e. ammonia emerges from the SCR catalytic converter. This in turn causes a rise in the value measured by the NO_x sensor. The aim, therefore, is to achieve a minimum of the sensor value.

This, however, is a long-term adaptation and not a short-term control process as the SCR catalytic converter performs a storage function for ammonia.

During normal operation, the signal from the NO_x sensor before the SCR catalytic converter is used for the purpose of calculating the quantity. This sensor determines the quantity of nitrogen oxide in the exhaust gas and sends the corresponding value to the DDE.

However, the NO_x sensor must reach its operating temperature before it can start measuring. Depending on the temperature, this can take up to 15 minutes. Until then the DDE uses a substitute value to determine the amount of nitrogen oxide in the exhaust gas.

A second NO_x sensor is installed after the SCR catalytic converter for the purpose of monitoring the system. It measures whether there are still nitrogen oxides in the exhaust gas. If so the injected quantity of the urea-water solution is correspondingly adapted.

Metering System Control

The metering system control could be considered as the executing part. It carries out the requirements set by the metering strategy.

This includes both the metering, i.e. injection as well as the supply of the urea-water solution.

The tasks of the metering system control during normal operation are listed in the following:

Metering of the urea-water solution:

- Implementation of the required target quantity of urea-water solution
- Feedback of the implemented actual quantity of urea-water solution.

Supplying urea-water solution:

- Preparation of metering process (filling lines and pressure built-up) under corresponding ambient conditions (temperature)
- Emptying lines during afterrunning
- Heater actuation.

In addition, the metering system control recognizes faults, implausible conditions or critical situations and initiates corresponding measures.

Metering of the Urea-water Solution

The metering strategy determines the quantity of urea-water solution to be injected. The metering system control executes this request. A part of the function is metering actuation that determines the actual opening of the metering valve.

Depending on the engine load, the metering valve injects at a rate of 0.5 Hz to 3.3 Hz.

The metering actuation facility calculates the following factors in order to inject the correct quantity:

- The duty factor of the actuator of the metering valve in order to determine the injection duration
- Actuation delay to compensate for the reaction time of the metering valve.

The signal from the pressure sensor in the metering line is taken into account to ensure an accurate calculation; the pressure, however, should remain at a constant 5 bar.

The metering system control also calculates the quantity actually metered and signals this value back to the metering strategy.

The metering quantity is also determined over a longer period of time. This long-term calculation is reset during SCR refilling or can be reset by the BMW diagnosis system.

Supplying Urea-water Solution

A supply of a urea-water solution is required for the selective catalytic reduction process. It is necessary to store this medium in the vehicle and to make it available rapidly under all operating conditions. In this case “making available” means that the urea-water solution is applied at a defined pressure at the metering valve.

Various functions that are described in the following are required to carry out this task.

■ Heater

The system must be heated as the urea-water solution freezes at a temperature of -11°C .

The heating system performs following tasks:

- To monitor the temperature in the active reservoir and the ambient temperature
- To thaw a sufficient quantity of urea-water solution and the components required for metering the solution during system startup
- To prevent the relevant components freezing during operation
- To monitor the components of the heating system.

The following components are heated:

- Surge chamber in active reservoir
- Intake line in active reservoir
- Delivery module (pump, filter, reversing valve)
- Metering line (from active reservoir to metering module).

The heating systems for the metering line and delivery module are controlled dependent on the ambient temperature.

The heater in the active reservoir is controlled as a function of the temperature in the active reservoir.

The heating control is additionally governed by the following conditions:

Temperature in active reservoir and ambient temperature are the same				
	Condition 1	Condition 2	Condition 3	Condition 4
Ambient temperature and temperature in active reservoir	$> -4^{\circ}\text{C}$	$< -4^{\circ}\text{C}$	$< -5^{\circ}\text{C}$	$< -9^{\circ}\text{C}$
Metering line heater	Not active	Not active	Active	Active
Active reservoir heater	Not active	Active	Active	Active
Metering standby	Established	Established	Established	Delayed

Metering standby is delayed at a temperature below -9°C in the active reservoir; i.e. a defined waiting period is allowed to elapse until an attempt to build up pressure begins.

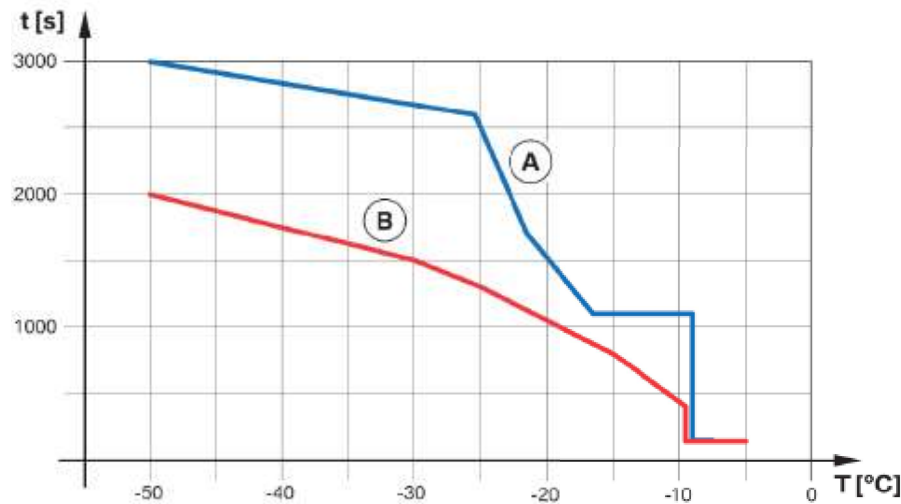
This time is constant from -9°C to -16.5°C as it is not possible to determine to what extent the urea-water solution is frozen.

At temperatures below -16.5°C , the heating time is extended until an attempt to build up the pressure is made. Heating the metering line generally takes place much faster.

Therefore, the temperature in the active reservoir is the decisive factor for the period of time until an attempt to build up the pressure is undertaken.

However, it is possible that the heating time for the metering line is longer at ambient temperature considerably lower than the temperature in the active reservoir. In this case, the ambient temperature is taken for the delay in metering standby.

The following graphic shows the delay as a function of the temperature sensor signals.



Index	Explanation	Index	Explanation
A	Delay as a function of temperature in active reservoir	B	Delay as a function of ambient temperature
t [s]	Delay time in seconds	T [°C]	Temperature in degrees Celsius

The graphic shows that, with the same temperature signals, the delay time relating to the temperature in the active reservoir is longer than the delay caused by the ambient temperature.

Only the times at temperatures below -9°C are relevant as they are shorter than 3 minutes at temperatures above -9°C. 3 minutes is the time that the entire system requires to establish metering standby (e.g. also taking into account the temperature in the SCR catalytic converter).

This is also the time that is approved by the EPA (Environmental Protection Agency) as the preliminary period under all operating conditions. This time is extended significantly at very low temperatures. The following example shows how the delay time up to metering standby is derived at low temperatures.

Example: Ambient temperature: -30°C, temperature in active reservoir: -12°C The vehicle was driven for a longer period of time at very low ambient temperatures of -30°C. The heater in the active reservoir has thawed the urea-water solution.

The vehicle is now parked for a short period of time (e.g. 30 minutes). When restarted, the temperature in the active reservoir is now -12°C.

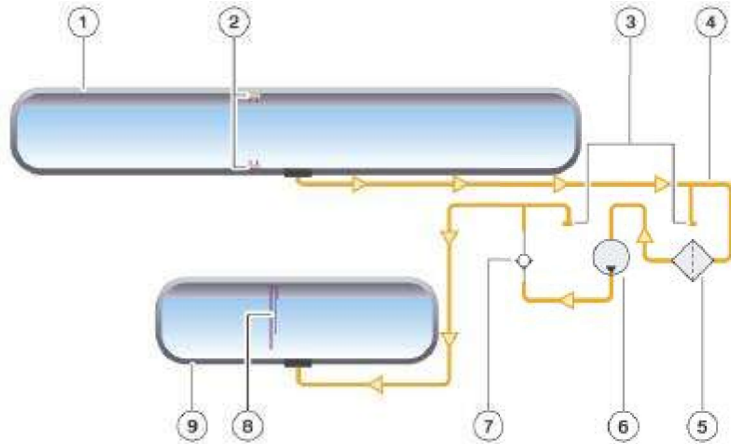
The delay time that is initiated by the temperature in the active reservoir is approximately 18 minutes while the delay time initiated by the ambient temperature is 25 minutes. Since the delay time initiated by the ambient temperature is longer, this will give rise to a longer delay.

Now another condition comes into play. Only the end of the delay caused by the temperature in the active reservoir can enable metering. This means:

- The delay time initiated by the temperature in the active reservoir will have elapsed after 18 minutes. No enable is yet provided by the second delay caused by the ambient temperature. A second cycle of 18 minutes now begins.
- The delay time initiated by the ambient temperature will elapse after 25 minutes and will send its enable signal. However, this delay cannot enable metering.
- The second cycle of the delay time caused by the temperature in the active reservoir will have elapsed after 36 minutes. Since the enable from the delay caused by the ambient temperature is now applied, metering will be enabled.

Transfer Pumping

So-called transfer pumping is required since two reservoirs are used for storing the urea-water solution. The term transfer pumping relates to pumping the urea-water solution from the passive reservoir into the active reservoir.



Index	Explanation	Index	Explanation
1	Passive reservoir	6	Pump
2	Level sensors	7	Non-return valve
3	Extractor connections	8	Level sensor
4	Transfer line	9	Active reservoir
5	Filter		

The following conditions must be met for transfer pumping:

- There is a urea-water solution in the passive reservoir
- The ambient temperature is above a minimum value of -5°C for at least 10 minutes
- A defined quantity (300 ml) was used up in the active reservoir or the reserve level in the active reservoir was reached.

The solution is then pumped for a certain time in order to refill the active reservoir. The transfer pumping procedure is terminated if the "full" level is reached before the time has elapsed.

If the passive reservoir was refilled, transfer pumping will only take place after a quantity of approximately 3 liters has been used up in the active reservoir. The entire quantity is then pumped over.

The system then waits again until a quantity of approximately 3 liters has been used up in the active reservoir before again pumping the entire quantity while simultaneously starting the incorrect refilling detection function.

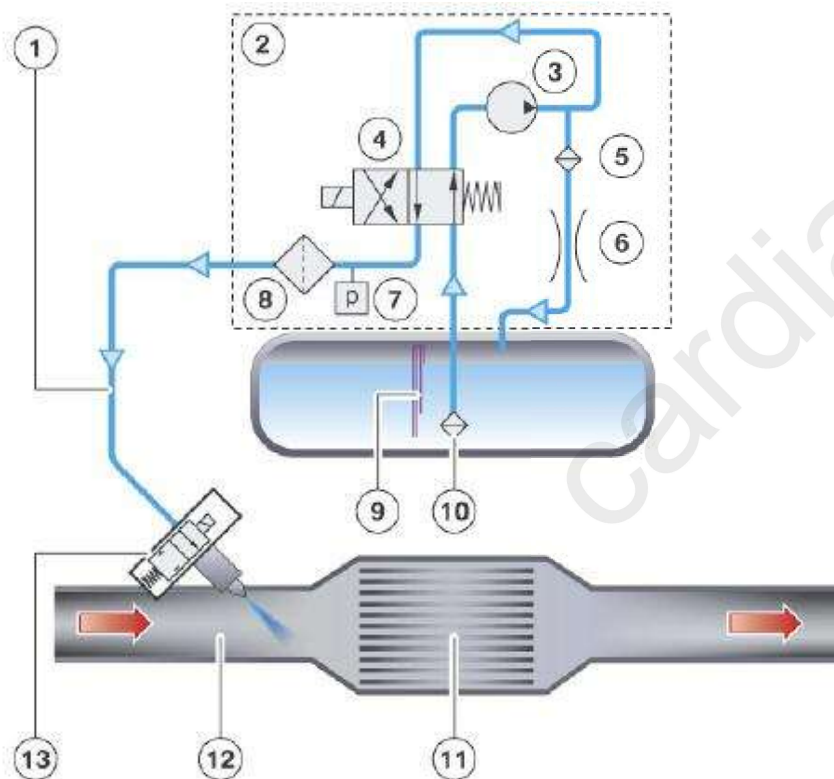
This function determines whether the system has been filled with the wrong medium as it is present in high concentration in the active reservoir.

Transfer pumping does not take place in the event of a fault in the level sensor system.

Delivery

The urea-water solution is delivered from the active reservoir to the metering module. This task is performed by a pump that is integrated in the delivery unit. The delivery unit additionally contains:

- Heater
- Pressure sensor
- Filter
- Return throttle
- Reversing valve.



Index	Explanation	Index	Explanation
1	Metering line	8	Filter
2	Delivery module	9	Level sensor
3	Pump	10	Filter
4	Reversing valve	11	SCR catalyst
5	Filter	12	Exhaust system
6	Restrictor	13	Metering module
7	Pressure sensor		

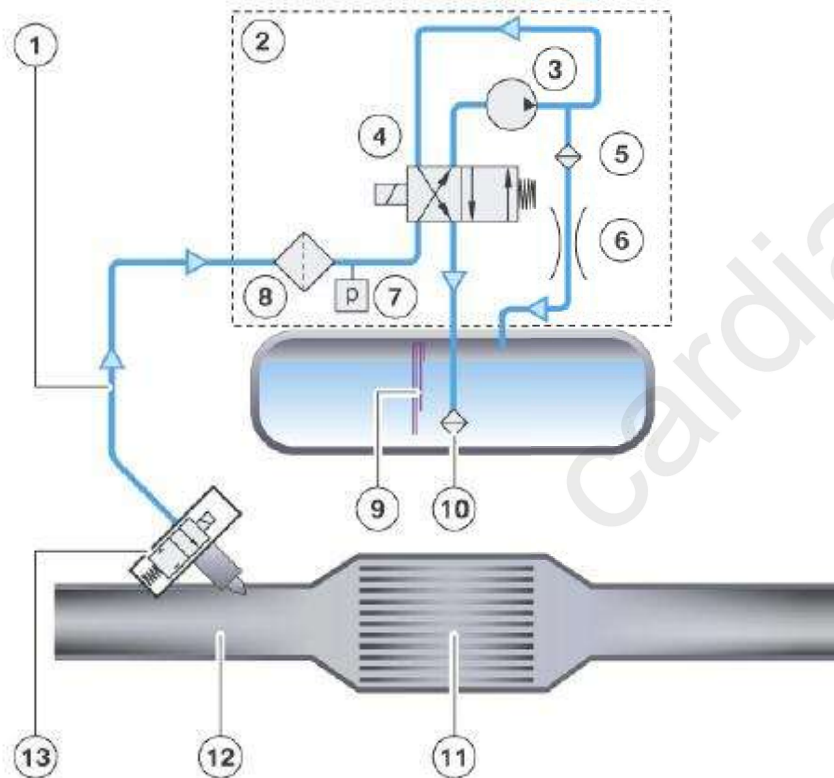
The pump is actuated by a pulse-width modulated signal (PWM signal) from the DDE. The PWM signal provides a speed specification for the purpose of establishing the system pressure. The value for the speed specification is calculated by the DDE based on the signal from the pressure sensor.

When the system starts up, the pump is actuated with a defined PWM signal and the line to the metering module is filled. This is followed by pressure build-up. Only then does pressure control take place.

When the metering line is filled, the opened metering valve allows a small quantity of the urea-water solution to be injected into the exhaust system.

During pressure control, i.e. during normal operation with metering, the pump is actuated in such a way that a pressure of 5 bar is applied in the metering line. Only a small part of the urea-water solution delivered by the pump is actually injected.

The majority of the solution is transferred via a throttle back into the active reservoir. This means, the delivery pressure is determined by the pump speed together with the throttle cross section.



Index	Explanation	Index	Explanation
1	Metering line	8	Filter
2	Delivery module	9	Level sensor
3	Pump	10	Filter
4	Reversing valve	11	SCR catalyst
5	Filter	12	Exhaust system
6	Restrictor (throttle)	13	Metering module
7	Pressure sensor		

The solution is injected four times per second. The quantity is determined by the opening time and stroke of the metering valve. However, the quantity is so low that there is no noticeable drop in pressure in the metering line.

■ Evacuating

After turning off the engine, the reversing valve switches to reverse the delivery direction of the pump, thus evacuating the metering line and metering module.

Evacuation also takes place if the system has to be shut down due to a fault or if the minimum temperature in the active reservoir can no longer be maintained.

This is necessary to ensure no urea-water solution remains in the metering line or metering module as it can freeze.

The metering valve is opened during evacuation.

Level Measurement

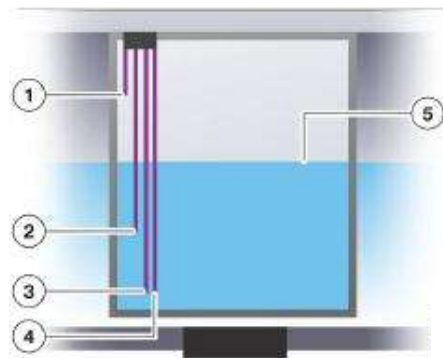
There are level sensors both in the active as well as in the passive reservoir. However, these sensors are not continuous sensors as in the fuel system for example. They can determine only a specific point, to which a defined quantity of urea-water solution in the reservoir is assigned.

Two separate level sensors are fitted in the passive reservoir, one for "full" and one for "empty". The signals from the level sensors are not sent directly to the DDE but rather to an evaluator.

The active reservoir contains one level sensor that has various measuring points:

- Full
- Warning
- Empty.

Also in this case, there is an evaluator installed between the sensors and the DDE, which fulfils the same tasks as for the passive reservoir.



Index	Explanation
1	Measuring point "full"
2	Measuring point "warning"
3	Measuring point "empty"
4	Reference
5	Level

This evaluator sends a plausible level signal to the DDE. It recognizes changes in the fill level caused, for example, by driving uphill/downhill or sloshing of the liquid as opposed to an actual change in the liquid level in the reservoir.

Low level is therefore signalled when the corresponding sensor is no longer covered by the urea-water solution for a defined period of time. Once the level drops below this value, it can no longer be reached during normal operation. This means, the liquid sloshing on the sensor or driving uphill/downhill is no longer interpreted as a higher liquid level.

Level of urea-water solution	Level signal
Level > Full	Full
Full > Level > Warning	OK
Warning > Level > Empty	Warning
Empty > Level	Empty

The level measurement system must also recognize when the active and passive reservoirs are refilled. This is achieved by comparing the current level with the value last stored.

The level sensor signal after refilling corresponds to the signal while driving uphill. To avoid possible confusion, the refilling recognition function is limited to a certain period of time after starting the engine and driving off - as it can be assumed that refilling will only take place while the vehicle is stationary.

A certain vehicle speed must be exceeded to ensure that sloshing occurs, thus providing a clear indication that the system has been refilled.

Refilling the system while the engine is running can also be detected but with modified logic. The signals sent by the sensors while the vehicle is stationary are also used for this purpose. The vehicle must be stationary for a defined minimum period in order to make the filling plausible.

When the urea-water solution is frozen, a level sensor will show the same value as when it is not wetted/covered by the solution. A frozen reservoir is therefore shown as empty. For this reason, the following sensor signals are used for measuring the level:

- Ambient temperature
- Temperature in active reservoir
- Heater enable.

■ Level Calculation

This function calculates the quantity of urea-water solution remaining in the active reservoir. The calculation is calibrated together with the level measurement.

Every time the level drops below a level sensor the corresponding amount of urea-water solution in the reservoir is stored. The amount of urea-water solution actually injected is then subtracted from this value while the pumped quantity is added.

This makes it possible to determine the level more precisely than that would be possible by simple measurement. In addition, the level can still be determined in the event of one of the level sensors failing.

Since it is possible that refilling is not recognized, the calculation is continued only until the level ought to drop below the next lower sensor.

Example:

Once the level drops below the "full" level sensor, for example, from now on the quantity of used and repumped urea-water solution is taken into account and the actual level below "full" calculated.

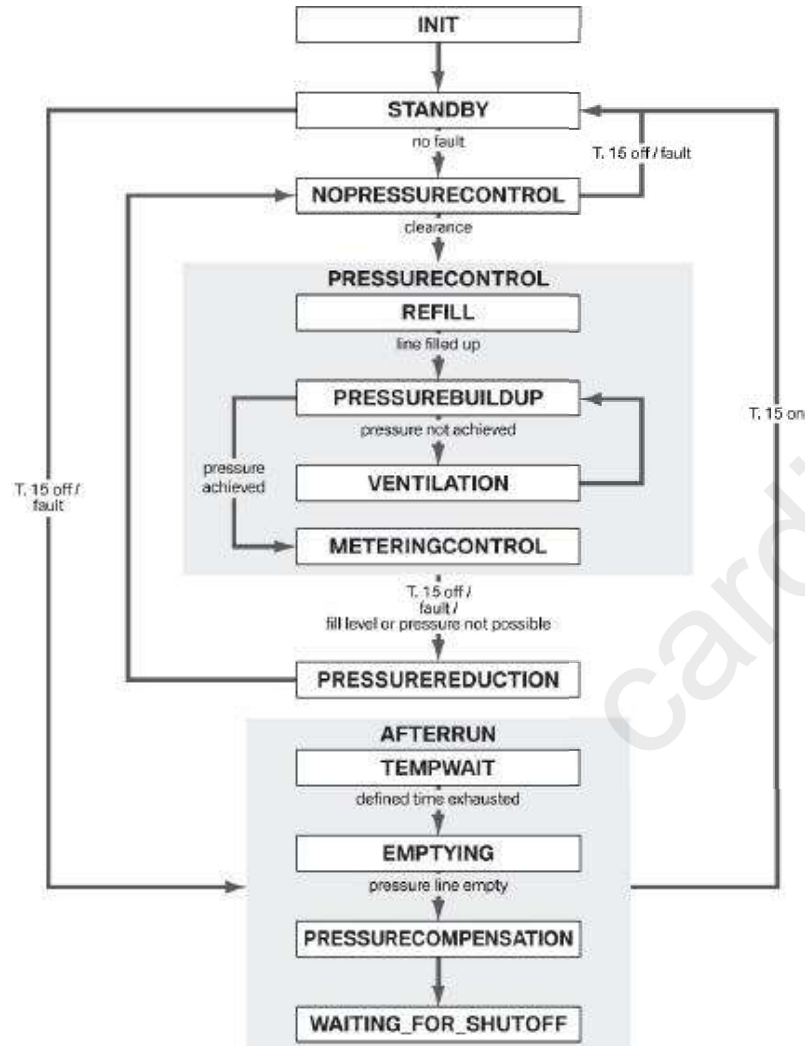
Normally, the level then drops below the next lower level sensor at the same time as determined by the level calculation. An adjustment takes place at this point and the calculation is restarted.

If, however, a quantity of urea-water solution is refilled without it being detected, the actual level will be higher than the calculated level. The level calculation is stopped if it calculates that the level ought to have dropped below the next level sensor but the level sensor is still wetted/covered.

By way of exception, a defective level sensor can cause the calculation to continue until the reservoir is empty.

SCR System Modes

When the ignition is switched on, the SCR control undergoes a logical sequence of modes in the DDE. There are conditions that initiate the change from one mode to the other. The following graphic shows the sequence of modes which are subsequently described.



INIT (SCR initialization)

The control unit is switched on (terminal 15 ON) and the SCR system is initialized.

STANDBY (SCR not active)

STANDBY mode is assumed either after initialization or in the case of fault. **AFTERRUN** mode is assumed if terminal 15 is switched off in this state or a fault occurs.

NOPRESSURECONTROL

(waiting for enable for pressure control)

NOPRESSURECONTROL mode is assumed when no faults occur in the system. In this mode, the system is waiting for the pressure control enable that is provided by the following sensor signals:

- Temperature in catalytic converter
- Temperature in active reservoir
- Ambient temperature
- Engine status (engine running).

The system also remains in NOPRESSURECONTROL mode for a minimum period of time so that a plausibility check of the pressure sensor can be performed.

PRESSURECONTROL mode is assumed once the enable is finally given. STANDBY mode is assumed if terminal 15 is switched off or a fault occurs in NOPRESSURECONTROL mode.

PRESSURECONTROL (SCR system running)

PRESSURECONTROL mode is the normal operating status of the SCR system and has four submodes.

PRESSURECONTROL mode is maintained until terminal 15 is switched off. A change to PRESSUREREDUCTION mode then takes place. A change to PRESSUREREDUCTION mode also takes place if a fault occurs in the system.

The four submodes of PRESSURECONTROL are described in the following:

- **REFILL**

The delivery module, metering line and the metering module are filled when REFILL mode is assumed. The pump is actuated and the metering valve opened by a defined value. The fill level is calculated.

The mode changes to PRESSUREBUILDUP when the required fill level is reached or a defined pressure increase is detected.

PRESSUREREDUCTION mode is assumed if terminal 15 is switched off or a fault occurs in the system.

- **PRESSUREBUILDUP**

In this mode, the pressure is built up to a certain value. For this purpose, the pump is actuated while the metering valve is closed.

If the pressure is built up within a certain time, the system switches to the next mode of METERINGCONTROL. If the required pressure built-up is not achieved after the defined period of time has elapsed, a status loop is initiated, and VENTILATION mode is assumed.

If the pressure cannot be built up after a defined number of attempts, the system signals a fault and assumes PRESSUREREDUCTION mode.

PRESSUREREDUCTION mode is also assumed when terminal 15 is switched off or another fault occurs in the system.

- **VENTILATION**

If the pressure could not be increased beyond a certain value in PRESSUREBUILDUP mode, it is assumed that there is still air in the pressure line.

The metering valve is opened for a defined period of time to allow this air to escape. This status is exited after this time has elapsed and the system returns to PRESSUREBUILDUP mode. The loop between PRESSUREBUILDUP and VENTILATION varies corresponding to the condition of the reducing agent. The reason for this is that a different level is established after REFILL depending on the ambient conditions. Repeating the ventilation function will ensure that the pressure line is completely filled with reducing agent. PRESSUREREDUCTION mode is assumed if terminal 15 is switched off or a fault occurs in the system.

- **METERINGCONTROL**

The system can enable metering in METERINGCONTROL mode. This is the actual status during normal operation. The urea-water solution is injected in this mode. In this mode, the pump is actuated in such a way that a defined pressure is established. This pressure is monitored. If the pressure progression overshoots or undershoots defined parameters, a fault is detected and the system assumes PRESSUREREDUCTION mode. These faults are reset on return to METERINGCONTROL mode.

PRESSUREREDUCTION mode is also assumed if terminal 15 is switched off or another fault occurs in the system.

PRESSUREREDUCTION

Metering enable is cancelled on entering PRESSUREREDUCTION mode.

This status reduces the pressure in the delivery module, metering line and the metering module after PRESSURECONTROL mode. For this purpose, the reversing valve is opened and the pump actuated at a certain value, the metering valve is closed.

PRESSUREREDUCTION mode ends when the pressure drops below a certain value. The system assumes NOPRESSURECONTROL mode if the pressure threshold is reached (undershot) within a defined time.

The system signals a fault if the pressure does not drop below the threshold after a defined time has elapsed. In this case or also in the case of another fault, the system assumes NOPRESSURECONTROL mode. NOPRESSURECONTROL mode is also assumed when terminal 15 is switched on.

AFTERRUN

The system is shut down in AFTERRUN mode. If terminal 15 is switched on again before afterrun has been completed, afterrun is cancelled and STANDBY mode is assumed. If this is not the case the system goes through the submodes of AFTERRUN.

- **TEMPWAIT (catalytic converter cooling phase)**

In AFTERRUN mode, TEMPWAIT submode is initially assumed if the system is filled. This is intended to prevent excessively hot exhaust gasses being drawn into the SCR system.

The duration of the cooling phase is determined by the exhaust gas temperature. EMPTYING submode is assumed after this time, in which the exhaust system cools down, has elapsed. EMPTYING submode is also assumed if a fault occurs in the system. If terminal 15 is switched on in this status, STANDBY mode is assumed.

- **EMPTYING**

The system assumes AFTERRUN_EMPTYING submode after the cooling phase. The pressure line and the delivery module are emptied in this submode. The urea-water solution is drawn back into the active reservoir by opening the reversing valve, actuating the pump and opening the metering valve.

This is intended to prevent the urea-water solution freezing in the metering line or the metering module. The level in the metering line is calculated in this mode.

PRESSURECOMPENSATION mode is assumed if the metering line is empty. PRESSURECOMPENSATION mode is also assumed if a fault occurs in the system. If terminal 15 is switched on, STANDBY mode is assumed.

- **PRESSURECOMPENSATION
(intake line - ambient pressure)**

After the system has been completely emptied, PRESSURECOMPENSATION submode is assumed. In this status the pump is switched off, the reversing valve is then closed followed by the metering valve after a delay. The time interval between switching off the pump and closing the valve prevents a vacuum forming in the intake line; pressure compensation between the intake line and ambient pressure takes place.

After executing the steps correctly the system assumes WAITING_FOR_SHUTOFF submode. WAITING_FOR_SHUTOFF is also assumed if a fault occurs in the system. If terminal 15 is switched on, STANDBY mode is assumed.

- **WAITING_FOR_SHUTOFF (shutting down SCR)**

The control unit is shut down and switched off.

NOTES
PAGE

Warning and Shut-down Scenario

The SCR system is relevant to the vehicle complying with the exhaust emission regulations - it is a prerequisite for EPA approval.

If the system fails, the approval will be invalidated and the vehicle must no longer be operated. A very plausible case leading to the system failure is that the urea-water solution runs out.

Vehicle operation is no longer permitted without the urea-water solution, therefore, the engine will no longer start. To ensure the driver is not caught out, a warning and shut-down scenario is provided that begins at a sufficiently long time before the vehicle actually shuts down so that the driver can either conveniently top up the urea-water solution himself or have it topped up.

■ Warning Scenario

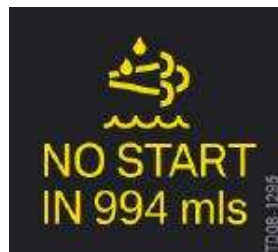
The warning scenario begins when the level drops below the "Warning" level sensor in the active reservoir. At this point, the active reservoir is still approximately 50% full with urea-water solution. The level is then determined as a defined volume (depending on type of vehicle).

From this point on, the actual consumption of the urea-water solution is subtracted from this value. The mileage is recorded when the amount of 2500 ml is reached.

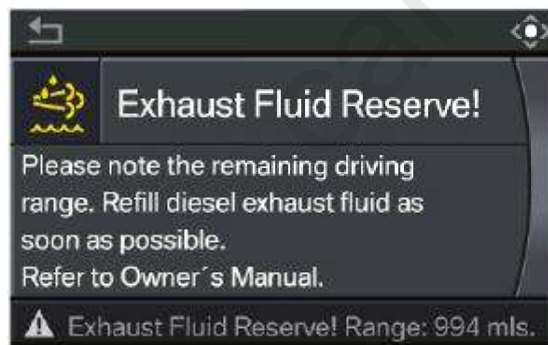
A countdown from 1000 mls now takes place irrespective of the actual consumption of the urea-water solution. The driver receives a priority 2 (yellow) check control message showing the remaining range.

If the vehicle is equipped with an on-board computer (CID - Central Information Display), instruction will also be displayed. The driver receives a priority 1 (red) check control message as from 200 mls.

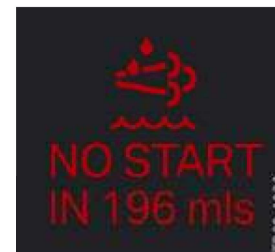
The following messages and indicators will be displayed:



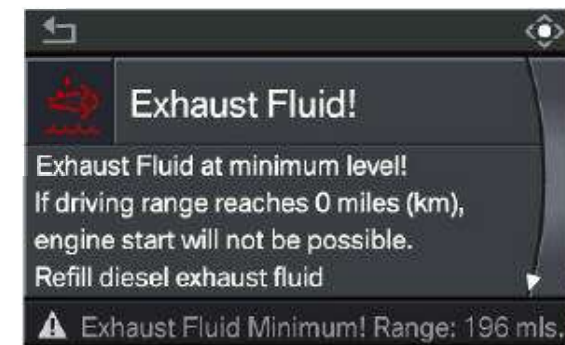
CC message in cluster, range < 1000 miles



CC message in CID, range < 1000 miles



CC message in cluster, range < 200 miles



CC message in CID, range < 200 miles

■ Shut-down Scenario

If the range reaches 0 mls, similar as to in the fuel gauge, three dashes are shown instead of the range. The check control message in the CID changes and shows that the engine can no longer be started.

In this case, it will no longer be possible to start the engine if it has been shut down for longer than three minutes. This is intended to allow the driver to move out of a hazardous situation if necessary.

If the system is refilled only after engine start has been disabled, the logic of the refill recognition system is changed in this special case, enabling faster refill.

■ Exhaust Fluid Incorrect

If the system is filled with an incorrect medium, this will become apparent after several hundred miles (kilometers) later by elevated nitrogen oxide values in the exhaust gas despite adequate injection of the supposed urea-water solution. The system recognizes an incorrect medium when certain limits are exceeded. From this point on, a warning and shut-down scenario is also initiated that allows a remaining range of 200 mls.

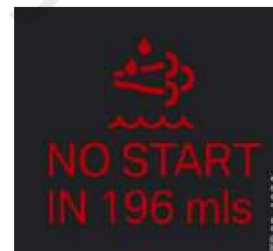
The exclamation mark in the symbol identifies the fault in the system. In this case, the message in the CID informs the driver to go to the nearest workshop.



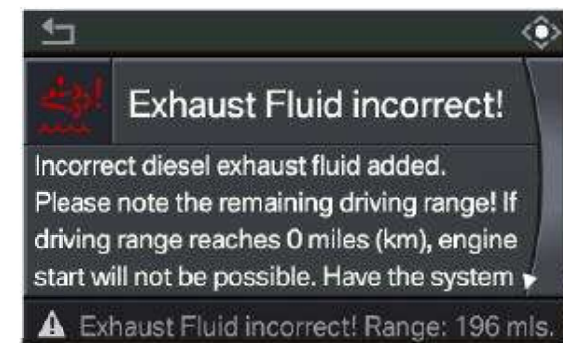
CC message in cluster, range = 0 miles



CC message in CID, range 0 miles



CC message in cluster, in case of incorrect DEF



CC message in CID, in case of incorrect DEF

Refilling

The active and passive reservoirs can be refilled with urea-water solution either by the service workshop or by the customer himself.

The system can be refilled without any problems with the vehicle on an incline of up to 5° in any direction. In this case, 90% of the maximum possible fill is still achieved.

The volume of the urea-water solution reservoir is designed such that the range is large enough to cover one oil change interval. This means the "normal" refill takes place as part of the servicing work in the workshop. If, however, the supply of urea-water solution should run low prematurely due to extraordinary driving profile, it is possible to top up a smaller quantity.

■ Refilling in Service Workshop

Refilling in the service workshop refers to the routine refill as part of the oil change procedure. This takes place at the latest after:

- 13000 mls on the E90,
- 11000 mls on the E70 or
- one year.

In this case, the system must be emptied first in order to remove older urea-water solution. This takes place via the extractor connections in the transfer line. Although a small residual quantity always remains in the reservoirs, it is negligible.

■ Topping Up

Any required quantity can be topped up if the urea-water solution reserve does not last up to the next oil change. Ideally, this quantity should only be as much as is required to reach the next oil change, as the system is then emptied.

Diesel Exhaust Fluid

The diesel exhaust fluid (DEF) is a urea-water solution which acts as a the carrier for the ammonia that is used to reduce the nitrogen oxides (NO_x) in the exhaust gas.

To protect persons and the environment from the effects of ammonia and to make it more easy to handle for transport and refuelling procedures, it is provided in an aqueous urea solution for the SCR process.

The recommended urea-water solution must meet certain standards for quality which are set forth in accordance with the DIN 70070/AUS32.

The DEF is a high-purity, water-clear, synthetically manufactured solution consisting of 32.5% urea with the balance being water (67.5%). The urea-water solution used must correspond to this standard.

■ Health and Safety

It is an aqueous solution which poses no special risks. It is not a hazardous substance and it is not a dangerous medium which is readily apparent after reviewing the Material Safety Data (MSDS) sheets.

The urea-water solution is not toxic. If small amounts of the product come in contact with the skin while handling the urea-water solution it is sufficient to simply rinse it off with ample water. In this way, the possibility of any ill effects on human health are ruled out.

The urea-water solution can be broken down by microbes and is therefore easily degradable. The urea-water solution poses a minimum risk to water and soil. Refer to local laws regarding handling and disposal requirements.

■ **Materials Compatibility**

Contact of urea-water solution with copper and zinc as well as their alloys and aluminum must be avoided as this leads to corrosion. No problems whatsoever are encountered with stainless steel and most plastics.

■ **Storage and Durability**

To avoid adverse effects on quality due to contamination and high testing expenditure, the urea-water solution should only be handled in storage and filling systems specifically designed for this purpose.

In view of the fact that the urea-water solution freezes solid at a temperature of -11°C and decomposes at an accelerated rate at temperatures above 25°C , the storage and filling systems should be set up in such a way that a temperature range from 30°C to -11°C is ensured.

Provided the recommended storage temperature of maximum 25°C is maintained, the urea-water solution meets the requirements stipulated by the standard DIN 70070 for at least 12 months after its manufacture.

This period of time is shortened if the recommended storage temperature is exceeded. The urea-water solution will become solid if cooled to temperatures below -11°C . When heated up, the frozen urea-water solution becomes liquid again and can be used without any loss in quality. Avoid direct UV radiation.

■ **Service Concerns**

When servicing SCR system components, absolute cleanliness is important. When cleaning any components, particularly those which contain the urea-water solution (DEF), it is important to use only "lint-free" cloths. Any lint can contaminate or clog SCR system components rendering the system inoperative.

Temperature Conversion Table

Temperature Conversion Table (Celsius/Fahrenheit)																													
C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F		
-40	-40	-23	-9.4	-6	21.2	11	51.8	28	82.4	45	113	62	143.6	79	174.2	96	204.8	113	235.4	130	266	147	296.6	164	327.2	181	357.7	198	388.3
-39	-38.2	-22	-7.6	-5	23	12	53.6	29	84.2	46	114.8	63	145.4	80	176	97	206.6	114	237.2	131	267.8	148	298.4	165	329	182	359.5	199	390.1
-38	-36.4	-21	-5.8	-4	24.8	13	55.4	30	86	47	116.6	64	147.2	81	177.8	98	208.4	115	239	132	269.6	149	300.2	166	330.8	183	361.3	200	391.9
-37	-34.6	-20	-4	-4	26.6	14	57.2	31	87.8	48	118.4	65	149	82	179.6	99	210.2	116	240.8	133	271.4	150	302	167	332.6	184	363.1	201	393.7
-36	-32.8	-19	-2.2	-2	28.4	15	59	32	89.6	49	120.2	66	150.8	83	181.4	100	212	117	242.6	134	273.2	151	303.8	168	334.4	185	364.9	202	395.5
-35	-31	-18	-0.4	-1	30.2	16	60.8	33	91.4	50	122	67	152.6	84	183.2	101	213.8	118	244.4	135	275	152	305.6	169	336.2	186	366.7	203	397.3
-34	-29.2	-17	1.4	0	32	17	62.6	34	93.2	51	123.8	68	154.4	85	185	102	215.6	119	246.2	136	276.8	153	307.4	170	338	187	368.5	204	399.10
-33	-27.4	-16	3.2	1	33.8	18	64.4	35	95	52	125.6	69	156.2	86	186.8	103	217.4	120	248	137	278.6	154	309.2	171	339.8	188	370.3	205	400.9
-32	-25.6	-15	5	2	35.6	19	66.2	36	96.8	53	127.4	70	158	87	188.6	104	219.2	121	249.8	138	280.4	155	311	172	341.5	189	372.1	206	402.7
-31	-23.8	-14	6.8	3	37.4	20	68	37	98.6	54	129.2	71	159.8	88	190.4	105	221	122	251.6	139	282.2	156	312.8	173	343.3	190	373.9	207	404.5
-30	-22	-13	8.6	4	39.2	21	69.8	38	100.4	55	131	72	161.6	89	192.2	106	222.8	123	253.4	140	284	157	314.6	174	345.1	191	375.7	208	406.3
-29	-20.2	-12	10.4	5	41	22	71.6	39	102.2	56	132.8	73	163.4	90	194	107	224.6	124	255.2	141	285.8	158	316.4	175	346.9	192	377.5	209	408.1
-28	-18.4	-11	12.2	6	42.8	23	73.4	40	104	57	134.6	74	165.2	91	195.8	108	226.4	125	257	142	287.6	159	318.2	176	348.7	193	379.3	210	409.9
-27	-16.6	-10	14	7	44.6	24	75.2	41	105.8	58	136.4	75	167	92	197.6	109	228.2	126	258.8	143	289.4	160	320	177	350.5	194	381.1	211	411.7
-26	-14.8	-9	15.8	8	46.4	25	77	42	107.6	59	138.2	76	168.8	93	199.4	110	230	127	260.6	144	291.2	161	321.8	178	352.3	195	382.9	212	413.5
-25	-13	-8	17.6	9	48.2	26	78.8	43	109.4	60	140	77	170.6	94	201.2	111	231.8	128	262.4	145	293	162	323.6	179	354.1	196	384.7	213	415.3
-24	-11.2	-7	19.4	10	50	27	80.6	44	111.2	61	141.8	78	172.4	95	203	112	233.6	129	264.2	146	294.8	163	325.4	180	355.9	197	386.5	214	417.1

Temperature Conversion Table (cont.)

Temperature Conversion Table (Celsius/Fahrenheit)																													
C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F		
215	419	232	449.6	249	480.2	266	510.8	283	541.4	300	572	317	602.6	334	633.2	351	663.8	368	694.4	385	725	402	755.6	419	786.2	436	816.8	453	847.4
216	420.8	233	451.4	250	482	267	512.6	284	543.2	301	573.8	318	604.4	335	635	352	665.6	369	696.2	386	726.8	403	757.4	420	788	437	818.6	454	849.2
217	422.6	234	453.2	251	483.8	268	514.4	285	545	302	575.6	319	606.2	336	636.8	353	667.4	370	698	387	728.6	404	759.2	421	789.8	438	820.4	455	851
218	424.4	235	455	252	485.6	269	516.2	286	546.8	303	577.4	320	608	337	638.6	354	669.2	371	699.8	388	730.4	405	761	422	791.6	439	822.2	456	852.8
219	426.2	236	456.8	253	487.4	270	518	287	548.6	304	579.2	321	609.8	338	640.4	355	671	372	701.6	389	732.2	406	762.8	423	793.4	440	824	457	854.6
220	428	237	458.6	254	489.2	271	519.8	288	550.4	305	581	322	611.6	339	642.2	356	672.8	373	703.4	390	734	407	764.6	424	795.2	441	825.8	458	856.4
221	429.8	238	460.4	255	491	272	521.6	289	552.2	306	582.8	323	613.4	340	644	357	674.6	374	705.2	391	735.8	408	766.4	425	797	442	827.6	459	858.2
222	431.6	239	462.2	256	492.8	273	523.4	290	554	307	584.6	324	615.2	341	645.8	358	676.4	375	707	392	737.6	409	768.2	426	798.8	443	829.4	460	860
223	433.4	240	464	257	494.6	274	525.2	291	555.8	308	586.4	325	617	342	647.6	359	678.2	376	708.8	393	739.4	410	770	427	800.6	444	831.2	461	861.8
224	435.2	241	465.8	258	496.4	275	527	292	557.6	309	588.2	326	618.8	343	649.4	360	680	377	710.6	394	741.2	411	771.8	428	802.4	445	833	462	863.6
225	437	242	467.6	259	498.2	276	528.8	293	559.4	310	590	327	620.6	344	651.2	361	681.8	378	712.4	395	743	412	773.6	429	804.2	446	834.8	463	865.4
226	438.8	243	469.4	260	500	277	530.6	294	561.2	311	591.8	328	622.4	345	653	362	683.6	379	714.2	396	744.8	413	775.4	430	806	447	836.6	464	867.2
227	440.6	244	471.2	261	501.8	278	532.4	295	563	312	593.6	329	624.2	346	654.8	363	685.4	380	716	397	746.6	414	777.2	431	807.8	448	838.4	465	869
228	442.4	245	473	262	503.6	279	534.2	296	564.8	313	595.4	330	626	347	656.6	364	687.2	381	717.8	398	748.4	415	779	432	809.6	449	840.2	466	870.8
229	444.2	246	474.8	263	505.4	280	536	297	566.6	314	597.2	331	627.8	348	658.4	365	689	382	719.6	399	750.2	416	780.8	433	811.4	450	842	467	872.6
230	446	247	476.6	264	507.2	281	537.8	298	568.4	315	599	332	629.6	349	660.2	366	690.8	383	721.4	400	752	417	782.6	434	813.2	451	843.8	468	874.4
231	447.8	248	478.4	265	509	282	539.6	299	570.2	316	600.8	333	631.4	350	662	367	692.6	384	723.2	401	753.8	418	784.4	435	815	452	845.6	469	876.2