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Advanced Diesel Technology

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Advanced Diesel Technology

Model: E90 (335d) and E70 (XDrive35d)

Production: From September 2008

OBJECTIVES

After completion of this module you will be able to:

- Locate diesel related components
- Understand diesel emission control systems
- Understand Digital Diesel Electronics (DDE)
- Perform diesel engine and engine management diagnosis

Advanced Diesel Technology Introduction

U.S. Market Diesel Introduction

Beginning with model year 2009, BMW will introduce 2 diesel models for the first time since 1987. The E90 and E70 will be available with the new M57D30T2 (US) engine.

The two new models will meet the EPA Tier 2, Bin 5 requirements and will be considered "50 State" legal. In order to comply with these new stringent regulations, both vehicles have the latest in emission control and engine management technology.

Both vehicles will be equipped with the latest Selective Catalytic Reduction system to reduce unwanted NO_X emissions. Also, the X5 will have an additional Low Pressure EGR system to further assist in the reduction of NO_X.

The E90 will be known as the 335d, while the E70 will reflect the new naming strategy as the X5 "Xdrive35d".

In addition to having a new engine, the new diesel powered 3-series will also be considered a "face-lifted" version (or LCI) with other changes to be detailed in future training.

The new X5 Xdrive35d and 335d will be available in the late fall of 2008 with the same impressive six-cylinder diesel engine.

The provisional fuel economy data is as follows:

- 23/36 mpg (city/hwy) for the 335d
- 19/26 mpg (city/hwy) for the X5 (X Drive 35d)

Note: The above fuel economy data is provisional. The official EPA data is not currently available

A Diesel Engine for North America

Impressive power and performance as well as exemplary efficiency have contributed to making BMW diesel engines an attractive as well as future-oriented drive technology.

This technology is now being made available to drivers in North America. BMW is introducing this diesel technology to the USA and Canada under the name "BMW Advanced Diesel with Blue Performance".

The introduction is an integral part of the Efficient Dynamics development strategy, which has become a synonym for extremely low CO_2 emissions - not surprising when considering its extremely low fuel consumption.

Efficient Dynamics is not solely an instrument for reducing fuel consumption, but rather it is designed as an intelligent entity with increased dynamics. Not without good reason, the M57D30T2 engine is referred to as the world's most agile diesel engine.

In the 2008 International Engine of the Year Awards, the BMW diesel came in second in the 2.5 to 3.0 liter category. Surprisingly, the M57D30T2 engine finished second only to the gasoline powered N54 engine.

But, both the N54 and M57 diesel engines finished well ahead of the competition which included diesel engines from other manufacturers.

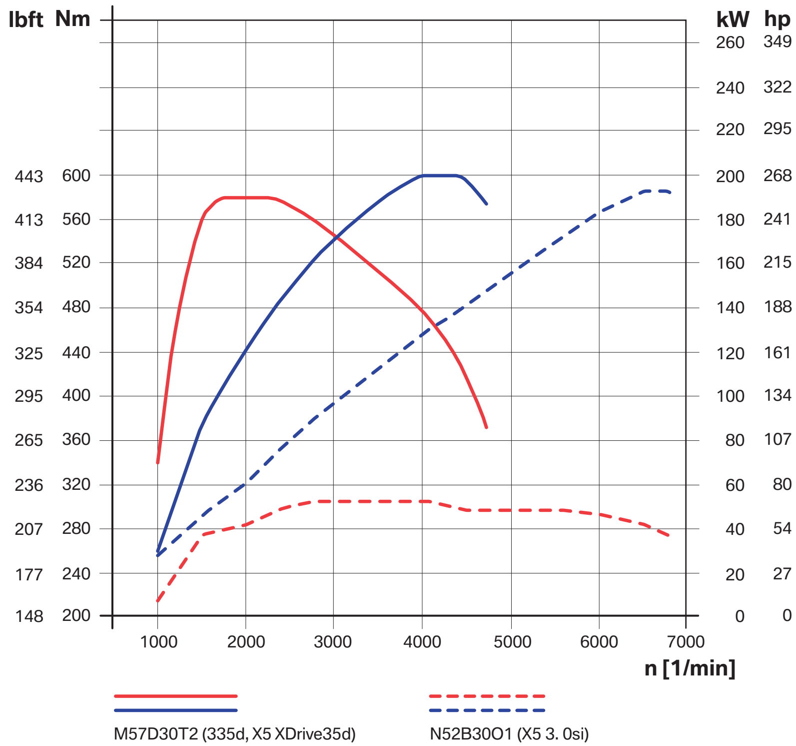
The following pages contain a comparison of the new BMW diesel engine technology to the current BMW gasoline engine technology.

Technical Data Comparison

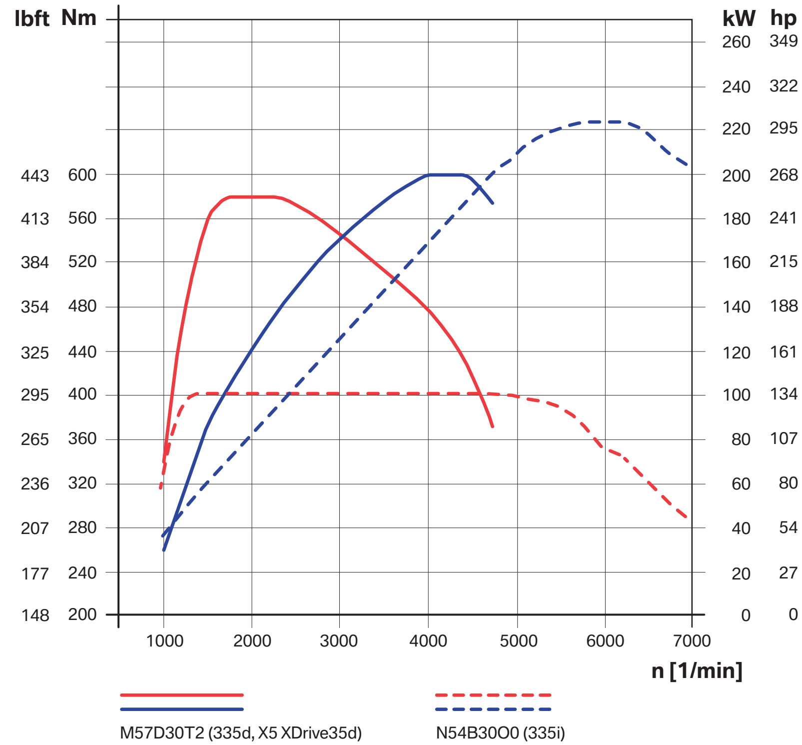
Description	Units of Measurement	N52B3O01	N54B30O0	N62B48O1	M57D30T2 (US)
Engine type		R6	R6	V-8	R6
Displacement	(cm3)	2996	2979	4799	2993
Firing order		1-5-3-6-2-4	1-5-3-6-2-4	1-5-4-8-6-3-7-2	1-5-3-6-2-4
Stroke	mm	88	88.9	88.3	90
Bore	mm	85	84	93	84
Power output @ rpm	hp @ rpm	260@6600	300 @ 5800	360 @ 6300	265 @ 4200
Torque @ rpm	Nm @ rpm	305@2500	400 @ 1300-5000	475 @ 3500	580 @ 1750
Maximum engine speed	rpm	7000	7000	6500	4800
Power output per liter	hp/liter	86.7	100	75	89.3
Compression ratio	ratio	10.7 : 1	10.2 : 1	10.5 : 1	16.5 : 1
Cylinder spacing	mm	91	91	98	91
Valves/cylinder		4	4	4	4
Intake valve	mm	34.2	31.4	35	27.4
Exhaust valve	mm	29	28	29	25.9
Main bearing journal diameter	mm	56	56	70	60
Connecting rod journal diameter	mm	50	50	54	45
Fuel specification (Octane)	(RON)	91-98	91-98	91-98	Diesel (Cetane 51)
Engine management		MSV80	MSD80	ME 9.2.2	DDE 7.3
Emission standard		ULEV II	ULEV II	ULEV II	ULEV II

Power Output Comparison

Diesel vs. N52



Diesel vs. N54



The following full load diagrams provide a comparison of the new diesel engine to the current production gasoline engines, both 6 and 8 cylinder.

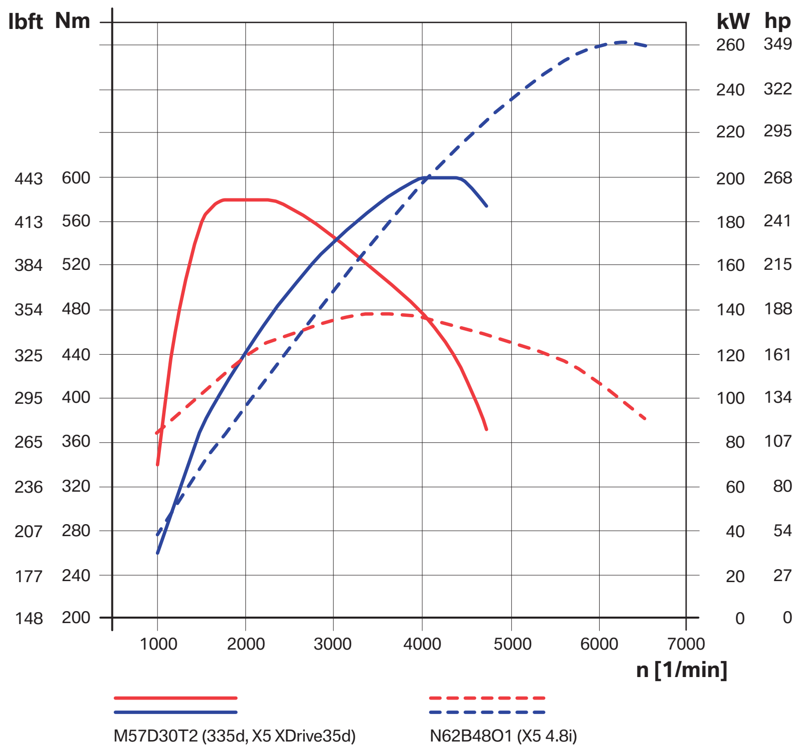
Most notably, the diesel has the advantage in the torque output. The above comparison shows a comparison between the N52 engine, which is a naturally aspirated 3-liter gasoline engine.

The power developed by the gasoline engine is carried over a broader RPM range, but the diesel has more output torque which is available at a much lower engine speed.

In the above graph, the N54 has a slight advantage in peak output with regard to horsepower. Since the N54 is a turbocharged engine, the output torque figures show the torque output at a lower engine speed, but it is quite “flat” up to almost 5000 RPM.

In contrast, the diesel has a much higher torque output, but is only available for a short time. After about 2400 RPM, the torque drops off considerably.

Comparison to the V8 Engine



The familiar N62B48O1 has impressive horsepower output but, even with 8-cylinders, it does not have the torque output of the M57 diesel engine.

Overall, these engine output graphs illustrate that the diesel has very specific characteristics especially with regard to torque output.

Vehicles with diesel engines are adapted to suit these torque characteristics with an upgraded torque converter and a rear axle gear ratio which allows the full utilization of the output curve.

In short, the new BMW diesel engine exceeds all of the currently available gasoline engines up to an engine speed of about 4000 rpm.

Workshop Exercise - Vehicle Walkaround

1. *Locate the following components on both vehicles (E70 and E90), look over both vehicles and fill in requested information:*

- ❑ Locate the dipstick on the E70 and E90.

  Why is one red and one black?

  ____

  ____

  ____

- ❑ Look at the method of oil checking between both vehicles

  What is the difference between the two?

  ____

  ____

  ____

- ❑ Locate the SCR fill points on both vehicles

  Where are they located?

  E70: ______________________________

  ____

  E90: ______________________________

  ____

- ❑ Locate the additional underbody paneling on the E90

- ❑ Locate SCR reservoirs (tanks) on both vehicle and note locations:

  E70: Passive Tank ______________________________

  ____

  Active Tank ______________________________

  E90: Passive Tank ______________________________

  ____

  Active Tank ______________________________

- ❑ Locate the fuel filter
- ❑ Locate the oil filter and drain plug locations
- ❑ Locate the air filters and housings
- ❑ Open the fuel filler door and remove cap, note differences
- ❑ Examine the DPF on both vehicles and note the differences
- ❑ Note the EGR system and the differences between E70 and E90
- ❑ Note the external appearance of the E70 and compare with gasoline version:

  How can you ID a diesel vehicle (without looking at the badges)?

  ____

  ____

- ❑ Note the external appearance of the E90 and compare with gasoline version:

  How can you ID a diesel vehicle (without looking at the badges)?

  ____

  ____

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Engine Mechanical

Engine Mechanical Changes

For the US market, several changes were incorporated into the M57 engine. Some of the components affected include:

- Bearings (crankshaft and connecting rod)
- Pistons
- Crankcase
- Crankcase ventilation

Bearings

The connecting rod bearings are now lead-free. The familiar sputter bearing arrangement is still used.

The upper (con rod side) bearing is a 3-layer sputter bearing. The cap side is a 2-layer non-sputter bearing.

The crankshaft main bearings are still the conventional 3-layer (lead-based) bearings.

Future engine designs will use completely “lead-free” bearings.

Pistons

The piston pin has a greater offset than in the European version. The offset of the piston pin means that the piston pin is slightly off center.

This provides acoustic advantages during changes in piston contact. The acoustic advantages of increasing the offset are further developed particularly at idle speed.

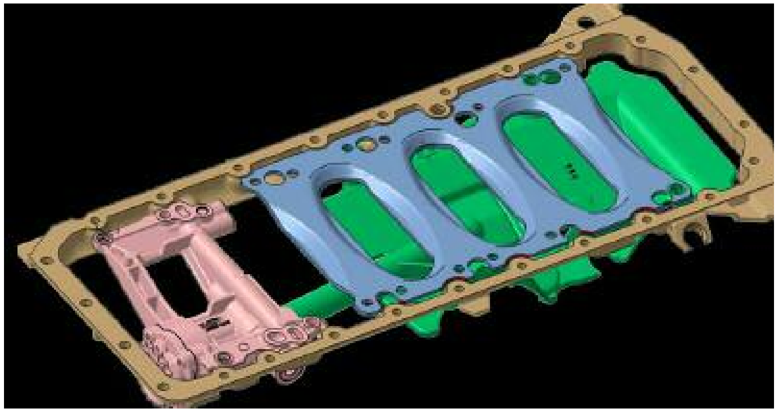
Crankcase

In contrast to the European version, the M57D30T2 US engine has a larger reinforcement panel on the underside of the crankcase.

The reinforcement panel now covers four of the main bearing blocks for the crankshaft. In principle, the reinforcement panel serves to enhance the stability of the crankcase.

However, the enlargement was realized solely for acoustic reasons.

Note: Never drive the vehicle without the reinforcement panel.



Crankcase Vent

The crankcase vent in the US version is heated. In addition, the operation of the crankcase breather is OBD monitored. This is because a leaking system would increase unwanted emissions.

Index	Explanation	Index	Explanation
1	Cylinder head cover	5	Filtered intake air
2	Blow-by heater connection (OBD)	6	Blow-by heater connection at blow-by pipe
3	Blow-by heater connection at wiring harness	7	Intake air to exhaust turbocharger
4	Filtered air pipe	8	Blow-by pipe

The only probable reason for a leak in the system would be that the blow-by pipe is not connected to the cylinder head cover. In order to facilitate protection of this situation by the OBD, the heating line is routed via a connector to the cylinder head cover (2).

Essentially, this connector serves only as a bridge so that actuation of the heating system is looped through. The plug connection is designed in such a way that correct contact is made only when the blow-by pipe has been connected correctly to the cylinder head cover, i.e. the contact for the heating system is not closed if the blow-by pipe is not connected to the cylinder head cover. The OBD system recognizes this situation as a fault.

Note: If the blow-by pipe is not connected to the cylinder head correctly, the OBD will activate the MIL (Malfunction Indicator Lamp).

Note:

When making repairs which concern malfunctions of the crankcase ventilation system. Or, if any repairs are made to a turbocharger which has leaked oil into the engine, be sure to remove any residual oil in the intake air system.

Failure to do so may result in an engine over-rev situation causing irreparable engine damage. In this case, the warranty may be affected.

Summary of Changes for the M57D30T2 (US)

The following table provides an overview of the special features of the M57D30T2 US engine. They are divided into various categories.

- New development signifies a technology that has not previously been used on BMW engines.
- Modification signifies a component that was specifically designed for the M57D30T2 US engine but does not represent a technical innovation.
- Adopted describes a component that has already been used in other BMW engines.

This information describes only the main modifications to the M57D30T2 engine compared to the European version as well as fundamental vehicle systems specific to diesel engines.

Component/System	New Development	Modification	Adopted	Remarks
Engine mechanical systems		X		Very few modifications have been made to the basic engine. The modifications that have been made focus mainly on ensuring smooth engine operation. A significant feature, however, is the OBD monitoring of the crankcase breather.
Air intake and exhaust systems	X			The most extensive changes were made to the air intake and exhaust system. For instance, low pressure exhaust gas recirculation (low pressure EGR) is used for the first time at BMW on the E70. In addition to other minor adaptations, there are substantial differences in the sensor and actuator systems.
Cooling system		X		In principle, the cooling system corresponds to that of the European versions, however, it has been adapted to hot climate requirements.

Component/System	New Development	Modification	Adopted	Remarks
High pressure fuel system		X		The functional principle of the fuel preparation system does not differ from that of the European version, however, individual components have been adapted to the different fuel specification.
Fuel supply system			X	The fuel supply system is vehicle-specific and corresponds to the European version. There are, however, significant differences to petrol engine vehicles.
Selective Catalytic Reduction System (SCR)	X			The SCR system is used for the first time at BMW. Nitrogen oxide emissions are drastically reduced by the use of a reducing agent that is injected into the exhaust system upstream of a special SCR catalytic converter. Since the reducing agent is carried in the vehicle, a supply facility, made up of two reservoirs, is part of this system
Engine electrical system			X	The engine is equipped with the new DDE7 (digital diesel electronics) control unit that will be used in the next generation diesel engines (N57). The preheater (glow plug) system also corresponds to the N57 engines.
Automatic transmission			X	The automatic transmission corresponds to that in the ECE variant of the X5 xDrive35d. The gearbox itself has already been used in the US version of the X5 4.8i, however, a different torque converter is used for the diesel model.

Vehicle Specific Diesel Changes

Diesel Vehicles for the US Market

Aside from the engine itself, there are several changes which have been made to the diesel versions of the 335d and X5. These changes are required to successfully adapt the diesel engine.

These changes are as follows:

- Transmission
- Rear differential
- Cooling system
- Climate control system (auxiliary PTC heater)
- Acoustic package

Transmission

In view of the high torque developed by the M57D30T2 engine, the GA6HP26TU gearbox is used, which is normally fitted behind 8-cylinder gasoline engines.

The transmission gear ratios have not been changed.

Twin Damper Torque Converter

The gearbox is identical to that used in the X5 4.8i; only the torque converter is different.

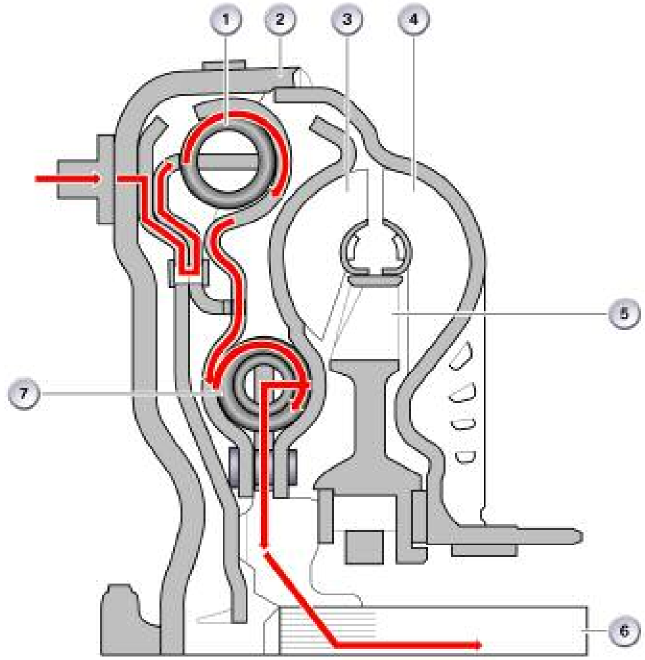
A so-called turbine torsional damper (TTD) is used while a twin damper torque converter is used for diesel engines.

In principle, the twin damper torque converter is a turbine torsional damper with a further damper connected upstream. The primary side of the first damper is connected to the converter lockup clutch while the secondary side is connected to the primary side of the second damper. As in the turbine torsional damper, the secondary side is fixed to the turbine wheel of the torque converter.

When the converter lockup clutch is open, the power flow is equal to that of the turbine torsional damper. The power is transferred from the turbine wheel via the second damper (but without damping) to the transmission input shaft.

When the converter lockup clutch is closed, the power is transmitted via the first damper that consists of an annular spring.
From here the power is transmitted to the second damper which operationally corresponds to the turbine torsional damper and also consists of two annular springs.

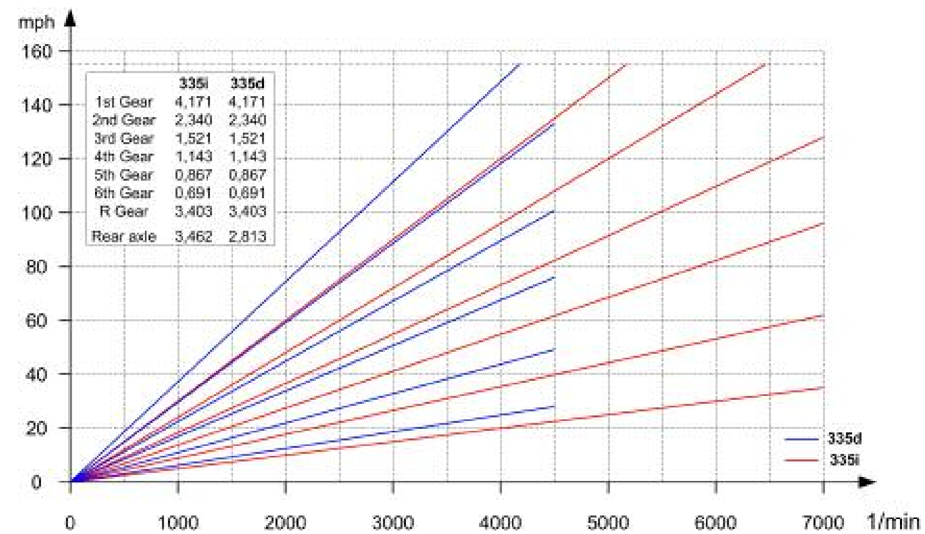
These further improved damping properties effectively adapt the transmission to the operational irregularities of the diesel engine.

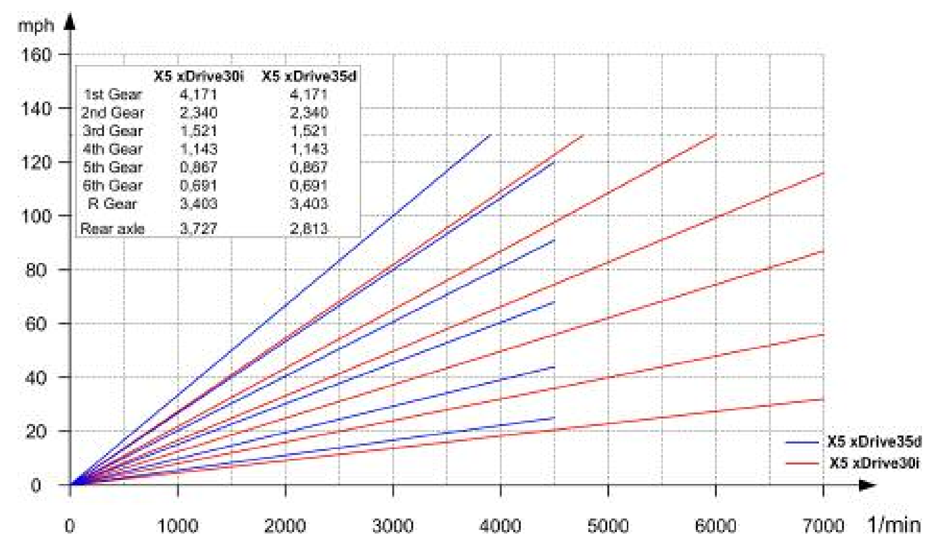


Index	Explanation	Index	Explanation
1	Annular spring	5	Stator
2	Converter housing	6	Transmission input shaft
3	Turbine wheel	7	Annular spring assembly
4	Impeller		

Rear Differential

In order to optimize the torque curve of the diesel engine, the differential ratio has been changed in the final drive. The ratio is now numerically lower which keep the RPM to an optimum level. The following charts show the comparisons of the transmission and final drive ratios between the gasoline and diesel versions.





Cooling System

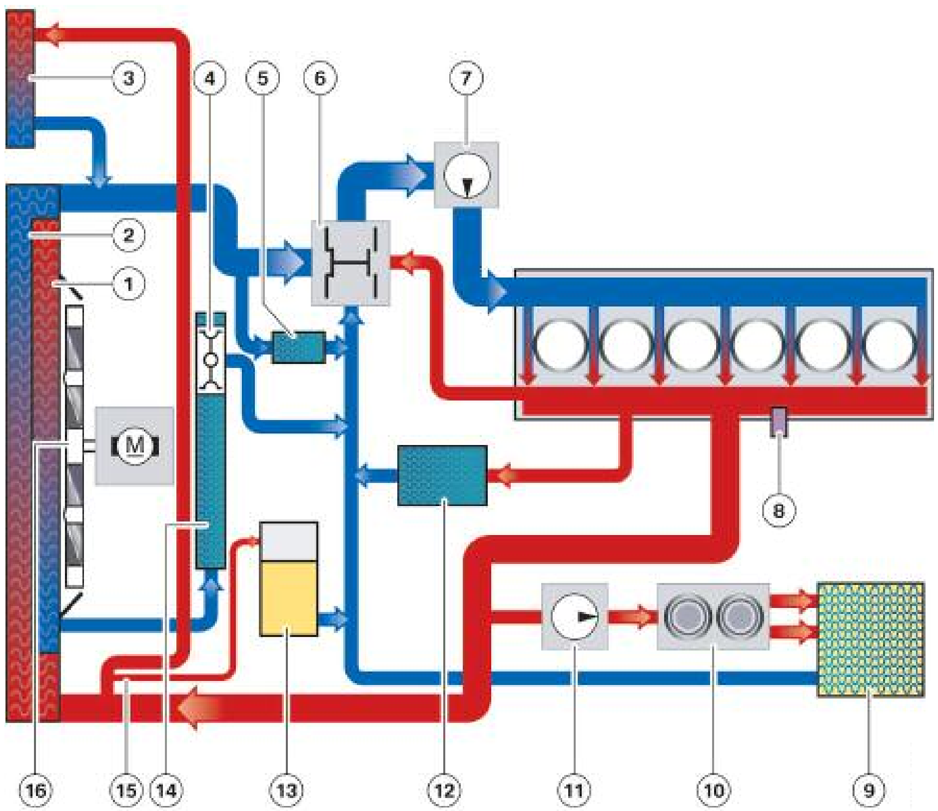
The cooling system, is in part, vehicle-specific. In principle, there are scarcely any differences between the cooling systems on petrol and diesel engines.

The two basic differences compared to a gasoline engine are:

- No characteristic map thermostat
- Addition of EGR cooler (LP and HP EGR).

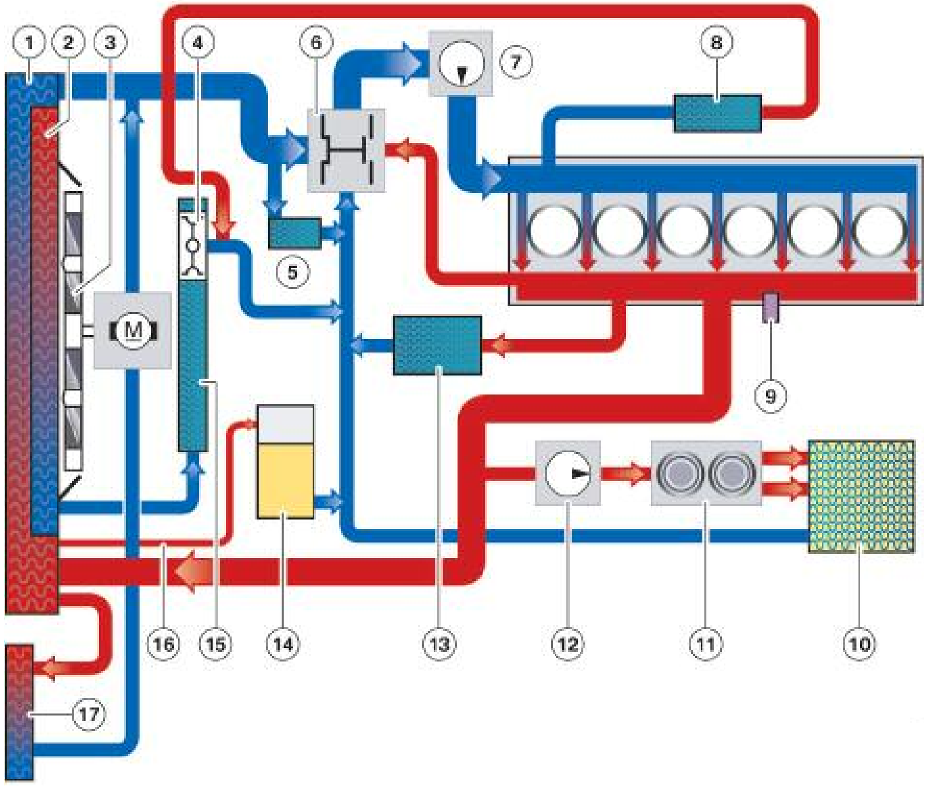
The E70 and E90 differ with regard to the EGR cooler. Since the E70 is equipped with a low pressure EGR system, it has a second EGR cooler, the low pressure EGR cooler.

Cooling System Overview - E90 Diesel



Index	Explanation	Index	Explanation
1	Transmission cooler (coolant to air)	9	Heater core (heat exchanger)
2	Radiator (coolant to air)	10	Water valve (dual)
3	Auxiliary radiator	11	Auxiliary coolant pump
4	Thermostat, transmission cooler	12	Engine oil cooler and engine oil to coolant heat exchanger
5	High pressure EGR cooler	13	Expansion tank
6	Thermostat	14	Transmission oil cooler and transmission oil to coolant heat exchanger
7	Coolant pump	15	Ventilation line
8	Coolant temperature sensor	16	Electric fan

Cooling System Overview - E70 Diesel



Index	Explanation	Index	Explanation
1	Radiator (coolant to air)	10	Heater core (heat exchanger)
2	Transmission cooler (coolant to air)	11	Water valve (dual)
3	Electric fan	12	Auxiliary coolant pump
4	Thermostat, transmission cooler	13	Engine oil cooler and engine oil to coolant heat exchanger
5	High pressure EGR cooler	14	Expansion tank
6	Thermostat	15	Transmission oil cooler and transmission oil to coolant heat exchanger
7	Coolant pump	16	Ventilation line
8	Low pressure EGR cooler	17	Auxiliary radiator
9	Coolant temperature sensor		

Cooling Method

The cylinder head varies according to the engineering used to implement the cooling concept.

There are 3 types of cooling concepts:

- Crossflow cooling
- Longitudinal flow cooling
- Combination of the two.

In BMW diesel engines only crossflow cooling is used. With cross-flow cooling, the coolant flows from the hot exhaust side of the cylinder head to the cooler inlet side.

This offers the advantage of even heat distribution throughout the cylinder head. By contrast, with longitudinal flow cooling, the coolant flows lengthways along the cylinder head, in other words from one end to the other.

As the coolant flows past each cylinder in succession, it becomes progressively hotter, resulting in very uneven heat distribution. This also causes pressure losses in the coolant circulation system.

A combination of both systems cannot outweigh the disadvantages of longitudinal flow cooling. Consequently, BMW diesel engines exclusively use crossflow cylinder head cooling.

Climate Control for Diesel Vehicles

The climate control system on the diesel vehicles is mostly identical to those on vehicles with gasoline engines. The major addition to the system is an electric auxiliary PTC heater. Both the E70 and E90 use an auxiliary PTC heater.

Since diesel engines are more thermally efficient than gasoline engines, the warmup time is increased. This can potentially cause a "comfort" related issue for the customer. So, this heater is needed to "boost" the output of the heater core until the coolant temperature is sufficient to provide the necessary heating.

The PTC heater does not heat the coolant, but rather the air passing through the heater core. The electric auxiliary heater is installed in the IHKA housing next to the heater core.

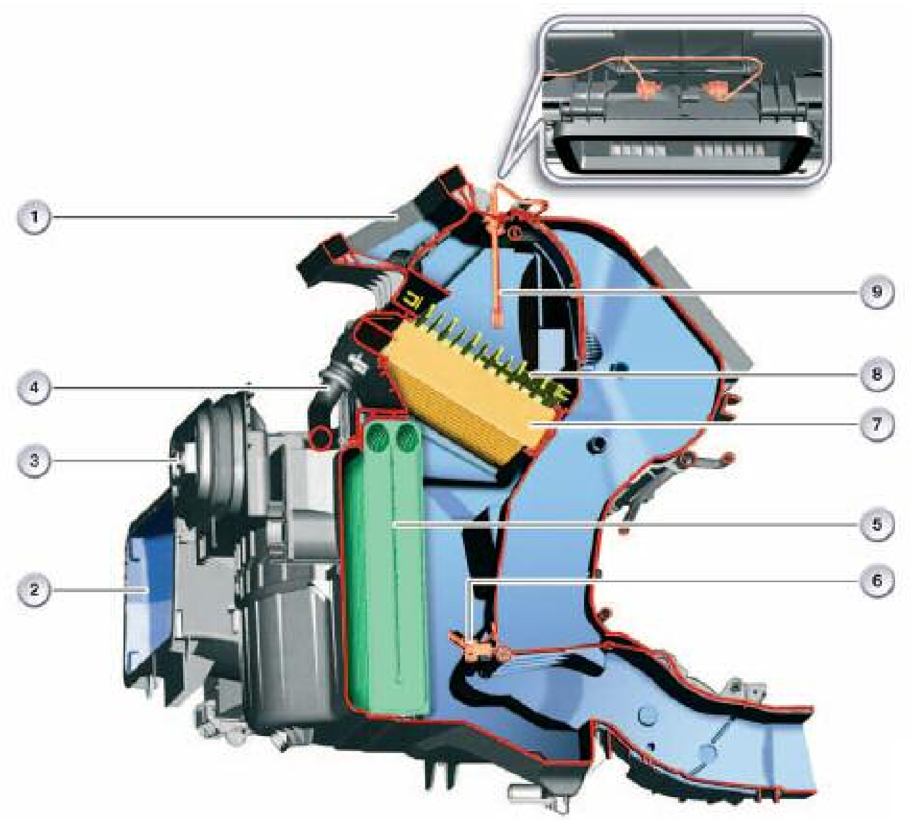
This is connected to the IHKA via the LIN bus and is controlled between 0 - 100% when heating is required (infinitely variable). The electric PTC auxiliary heater may only be operated using excess alternator power.

The power consumption can be limited via the DDE using power management. Notification of power availability is provided by the DDE via a CAN signal on the vehicle circuit and relayed to the electric PTC auxiliary heater by the IHKA via the LIN bus.

The output of the electric PTC auxiliary heater is 1250 W at a voltage of 13 V. The electric auxiliary heater consists of a heating grid and integrated actuation electronics.

The PTC heater has the following characteristics:

- Ceramic heating elements (PTC ceramic resistors)
- Access to air via metal grilles
- Actuation electronics.



Auxiliary PTC heater in A/C housing - E70

Index	Explanation	Index	Explanation
1	IHKA housing	6	Evaporator temperature sensor
2	Fresh air intake	7	Heat exchanger
3	Connection to expansion valve	8	PTC heater
4	Coolant connection to heat exchanger (heater core)	9	Temperature sensor for heat exchanger
5	Evaporator		

Front PTC Pin Assignments

The power connection and the signal connection are separate.

Power connection:

- Terminal 30
- Terminal 31.

Front PTC signal connection:

- Plug (3-pin)
- Terminal 15
- Generator load signal (PWM)
- LIN bus.

The electric PTC auxiliary heater has diagnostic capability for detecting faults such as:

- Missing contact
- Short circuit to ground and B+

The electronic system performs continuous self-diagnosis. This makes it possible to activate internal safety functions and make the diagnostic data available to the IHKA control unit via the LIN bus.

The following items have diagnostic capability:

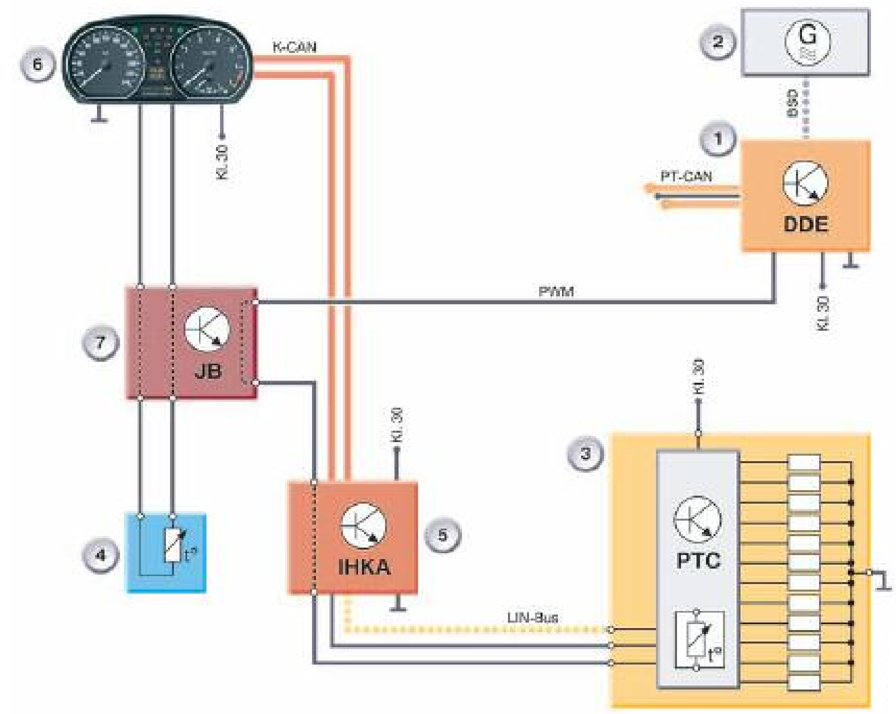
- Presence of power supply, terminal 15 and power supply voltage measurement
- Power output stage fault

The following safety functions are provided with the aid of self-diagnosis:

- PTC shut-off if the permitted operating voltage range is exceeded.

PTC Heater E90

PTC Heater s schematic - E90



Index	Explanation	Index	Explanation
1	DDE	5	IHKA control module
2	Alternator	6	Instrument cluster
3	PTC heater (with integrated electronics)	7	Junction box
4	Ambient temperature		

Acoustic Package

On the E90, there is additional paneling in the underbody below the engine. This paneling is used to further reduce any engine related noise which may emanate from the diesel engine.

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Diesel Engine Management

In contrast to the ECE version of the M57D30T2 engine, the US version of the engine electrical system features following differences:

- Engine control unit DDE7.3
- Preheating system with LIN-bus link and ceramic heater plugs
- Additional OBD sensors
- Electrically operated swirl flap and EGR valve
- Additional actuators and sensors for the low pressure EGR system.

Engine Control Module

The new DDE7.3 engine control module is used on the US version M57D30T2 engine. The DDE 7 version is used due to the fact that the DDE 6 engine control module was not sufficient to accommodate the addition of the SCR system as well as additional OBD functions.

DDE 7 will be used on future generations of diesel engines including the N57 which will be available sometime later.

Sensors and Actuators

In the M57D30T2 US engine, the modifications to the sensors and actuators are restricted to the air intake and exhaust system.

Several new components have been added to this system. The table below provides an overview. It shows a comparison between the E70 US and E90 US and the ECE variant (EURO4).

Sensors	EURO 4	E70 US	E90 US
Outside temperature sensor	X	X	X
Ambient pressure sensor	X	X	X
HFM	X	X	X
Intake air temp sensor (in HFM)	X	X	X
Charge air temperature sensor	X	X	X
Boost pressure sensor	X	X	X
Exhaust pressure sensor at exhaust manifold (before DPF)	X	X	X
Oxygen sensor	X	X	X
Exhaust gas temperature sensor before diesel oxidation catalyst (DOC)	X	X	X
Exhaust gas temperature sensor before diesel particulate filter (DPF)	X	X	X
Exhaust backpressure sensor before diesel particulate filter (DPF)	X	-	-
Exhaust differential pressure sensor	-	X	X
Temperature sensor after LP-EGR cooler	-	X	-
Temperature sensor after HP-EGR cooler	-	X	X
Exhaust gas temperature sensor before SCR catalyst	-	X	X
NO_X sensor before SCR catalyst	-	X	X
NO_X sensor after SCR catalyst	-	X	X
Positional feedback swirl flaps	-	X	X
Positional feedback HP-EGR valve	-	X	X
Positional feedback LP-EGR valve	-	X	-
Blow-by connection	-	X	X

Actuators	EURO 4	E70 US	E90 US
Compressor bypass valve	EUV	EUV	EUV
Turbine control valve	EPDW	EPDW	EPDW
Wastegate	EPDW	EPDW	EPDW
Throttle valve	EL	EL	EL
Swirl flaps	EUV	EL	EL
High pressure EGR valve	EPDW	EL	EL
Low pressure EGR valve	-	EPDW	-
Bypass valve for HP-EGR cooler	-	EUV	EUV
SCR metering valve		EL	EL

EL
Electrically actuated

EUV
Vacuum controlled via electric changeover valve (on/off)

EPDW
Vacuum controlled via electro-pneumatic pressure converter (PWM controlled)

OBD Monitored Functions

The engine management has the additional task of monitoring all exhaust-relevant systems to ensure they are functioning correctly. This task is known as On Board Diagnosis (OBD).

The malfunction indicator lamp (MIL) is activated if the onboard diagnosis registers a fault. The events specific to US diesel engines that cause the MIL to light up are described in the following.

Diesel Oxidation Catalyst

The oxidation catalytic converter is monitored with regard to its conversion ability which diminishes with aging. The conversion of hydrocarbons (HC) during cold start is used as the indicator as heat is produced as part of the chemical reaction and it follows a defined temperature progression after the oxidation catalytic converter.

The exhaust gas temperature sensor after the oxidation catalytic converter measures the temperature. The DDE maps the temperature progression during cold start and compares it to calculated models. The result determines how effective the oxidation catalytic converter is operating.

A reversible fault is stored if the temperature progression drops below a predetermined value. If this fault is still determined after two successive diesel particulate filter regeneration cycles, an irreversible fault is stored and the MIL is activated.

SCR Catalytic Converter

The effectiveness of the SCR catalytic converter is monitored by the two NO_X sensors. The nitrogen mass is measured before and after the SCR catalytic converter and a sum is formed over a defined period of time. The actual reduction is compared with a calculated value that is stored in the DDE.

The following conditions must be met for this purpose:

- NO_X sensors plausible
- Metering active
- Ambient temperature in defined range
- Ambient pressure in defined range
- Regeneration of diesel particulate filter not active
- SCR catalytic converter temperature in defined range (is calculated by means of exhaust temperature sensor before SCR catalytic converter)
- Flow of exhaust gas in defined range.

Monitoring involves four measuring cycles. A reversible fault is stored if the actual value is lower than the calculated value. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Long-term adaptation is implemented, where the metered quantity of urea-water solution is adapted, to ensure the effectiveness of the SCR catalytic converter over a long period of time. To execute this adaptation procedure, the signal of the NO_X sensor after the SCR catalytic converter is compared with a calculated value. If variations occur, the metered quantity is correspondingly adapted in the short term.

The adaptations are evaluated and a correction factor is applied to the metered quantity.

The operating range for the long-term adaptation is the same as that for effectiveness monitoring.

A reversible fault is stored if the correction factor exceeds a defined threshold. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Supplying Urea-water Solution
A supply of a urea-water solution is required to ensure efficient operation of the SCR catalytic converter.

Once the SCR catalytic converter has reached a certain temperature (calculated by the exhaust gas temperature sensor before the SCR catalytic converter), the metering control system attempts to build up pressure in the metering line.

For this purpose, the metering module must be closed and the delivery pump actuated at a certain speed for a defined period of time.

If the defined pressure threshold cannot be reached within a certain time, the metering module is opened in order to vent the metering line. This is followed by a new attempt to build up pressure.

A reversible fault is stored if a defined number of pressure build-up attempts remain unsuccessful. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

This monitoring takes place only once per driving cycle before metering begins. Continuous pressure monitoring begins after this monitoring run was successful.

A constant pressure of the urea-water solution (5 bar) is required for the selective catalytic reduction process. The actual pressure is measured by the pressure sensor in the delivery module and compared with a minimum and a maximum pressure threshold.

A reversible fault is stored if the limits are exceeded for a certain time. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

This monitoring run takes place while metering is active.

Level Measurement in Active Reservoir
A level sensor with three contacts at different heights is used for the active reservoir. The plausibility of the sensor is checked in the evaluator in that it checks whether the signals are logical.

For example, it is improbable that the "Full" contact is covered by the solution while the "Empty" contact is not. In this case, the evaluator sends a plausibility error to the DDE. This takes place at a pulse duty factor of 30% of the PWM signal. A reversible fault is set. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

This monitoring procedure only takes place if the temperature in the active reservoir is above a defined value.

If the line between the evaluator and at least one contact of the level sensor is interrupted, the fault is signalled to the DDE by a PWM signal with 40% pulse duty factor. A reversible fault is set.

If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Suitable Urea-water Solution
The SCR system is monitored with regard to refilling with an incorrect medium. This monitoring function starts when refilling is detected. Refilling detection is described in the section on the SCR system.

Effectiveness monitoring of the SCR catalytic converter is used for the purpose of determining whether an incorrect medium has been used. An incorrect medium is detected if the effectiveness drops below a certain value within a defined period of time after refilling.

A reversible fault is set in this case. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

In addition, the warning scenario with a remaining range of 200 mls is started.

NO_x Sensors

A dew point must be reached for effective operation and therefore also the monitoring of the NO_x sensor. This ensures that there is no longer any water in the exhaust system that could damage the NO_x sensors.

A reversible fault is set if the following monitoring functions detect a fault at the NO_x sensor. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

- Detection signal or correction factor incorrect
- Line break or short-circuit between measuring probe and control unit of NO_x sensor
- Measured value outside the defined range for a certain period of time
- Operating temperature is not reached after a defined heating time
- The distance from the measured value to zero is too great in overrun mode (no nitrogen oxides expected)
- During the transition from load to overrun mode, the signal of the NO_x sensor does not drop fast enough from 80% to 50% (only NO_x sensor before SCR catalytic converter)
- If, despite a peak in the signal of the NO_x sensor before the SCR catalytic converter, at least a defined change in the signal of the NO_x sensor after the SCR catalytic converter is not determined this is interpreted as implausible.

Exhaust Gas Recirculation (EGR)

During normal operation, the exhaust gas recirculation is controlled based on the EGR ratio. During regeneration of the diesel particulate filter, it is conventionally controlled based on the air mass.

The monitoring function also differs in this way: During normal operation a fault is detected when the EGR ratio is above or below defined limits for a certain period of time.

This applies to the air mass during regeneration of the diesel particulate filter. In order to monitor the high pressure EGR cooler, the temperature after the high pressure EGR cooler is measured with the bypass valve open and close with the engine running at idle speed. A fault is detected if the temperature difference is below a certain value.

For the low pressure EGR cooler (only E70), the measured temperature after the low pressure EGR cooler is compared with a calculate temperature for this position. A fault is detected if the difference exceeds a certain value.

Each of these faults is stored reversible. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Diesel Particulate Filter (DPF)
The diesel particulate filter is monitored by means of the differential pressure sensor. If the filter is defective, the differential pressure before and after the filter will be lower than for a new filter.

Monitoring starts when the flow of exhaust gas and the diesel particulate filter temperature exceed certain values. A fault is detected when the differential pressure drops below a defined threshold for a certain period of time.

Conversely, an overloaded/clogged diesel particulate filter is detected when the differential pressure exceeds a defined value for a certain period of time.

When regeneration of the diesel particulate filter is started, the time required until the exhaust temperature before the DPF reaches 250°C is measured. This time is set to zero if the engine runs for a longer period of time at idle speed or in overrun mode. A fault is detected if a defined time is exceeded before the temperature of 250°C is reached.

In this way, the response characteristics of the increase in exhaust temperature for DPF regeneration are monitored.

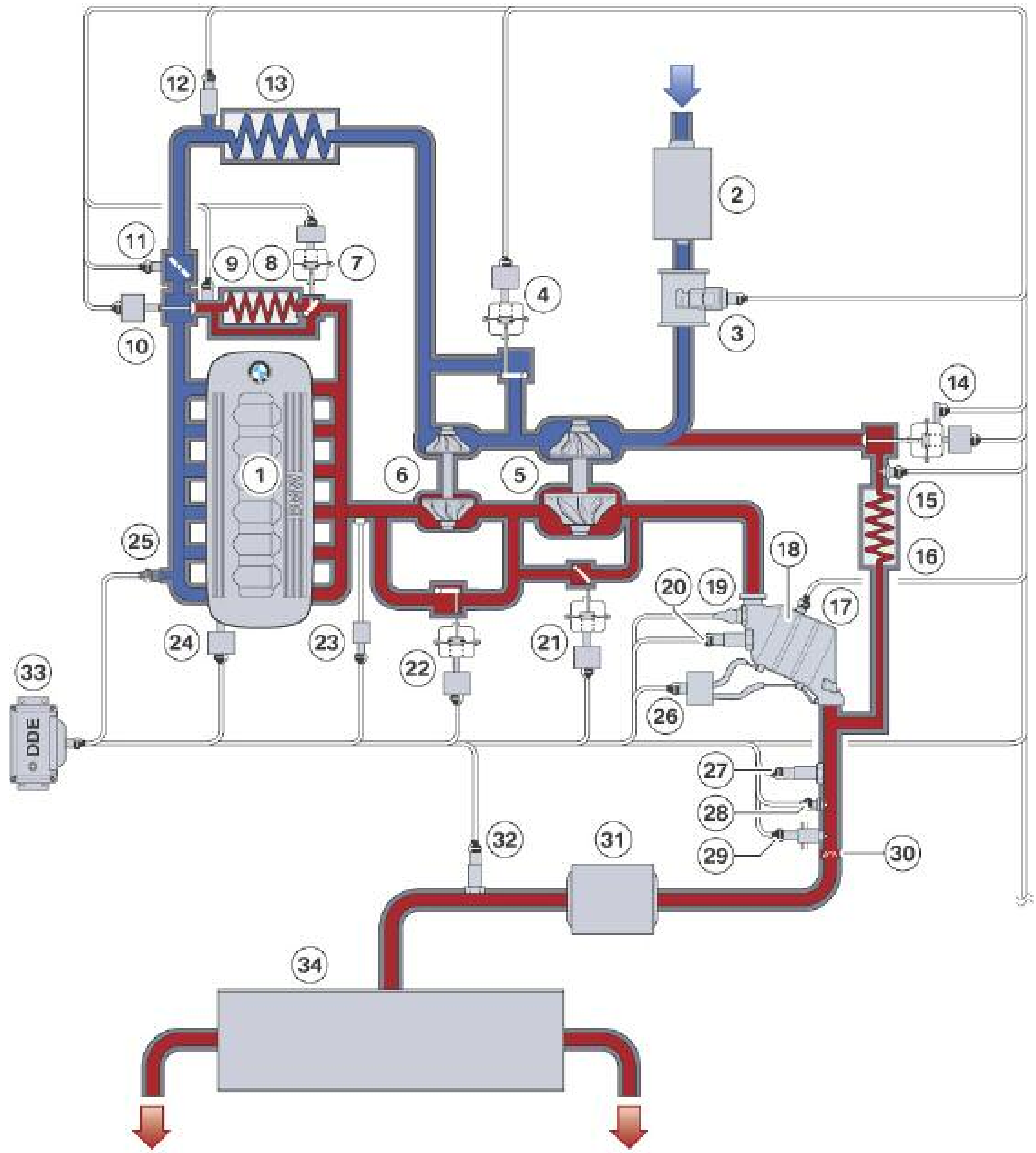
The system also monitors whether the exhaust gas temperature before the diesel particulate filter corresponds to the expected value after a defined period of time. If this is not the case although the control system has reached its limits, a fault is detected.

Also in this case, each of these faults is stored reversible. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Air Intake and Exhaust Systems

The M57D30T2 US engine exhibits the following special features in the air intake and exhaust system:

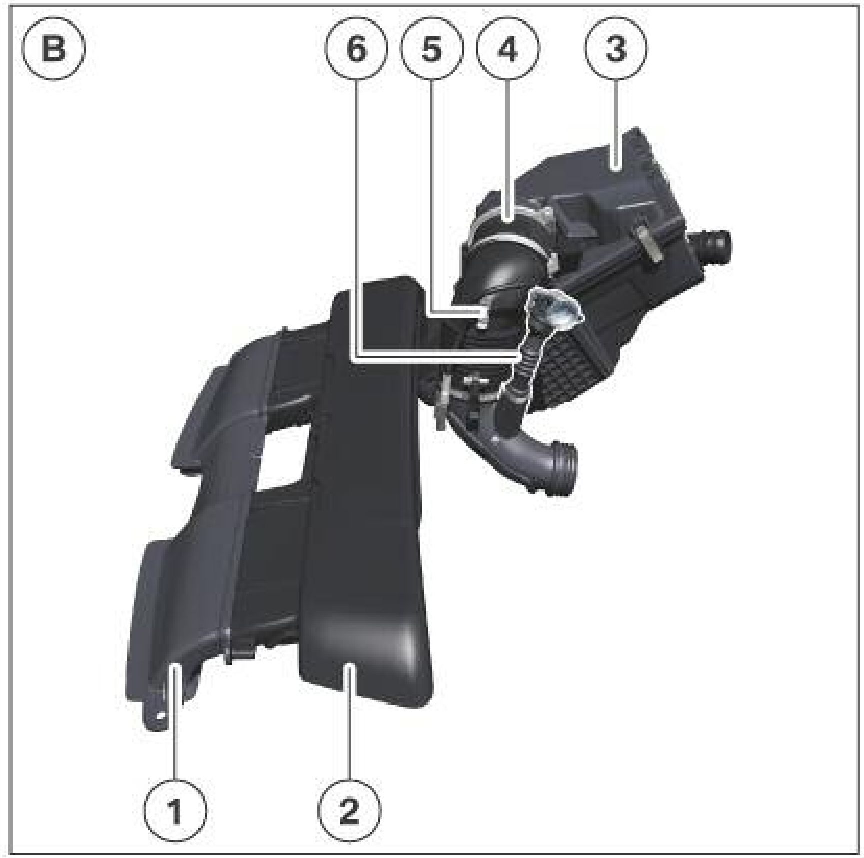
- Electric swirl flaps
- Electric exhaust gas recirculation valve (High pressure EGR valve)
- Low pressure EGR (E70 only)
- Turbo assembly adapted for low pressure EGR. (E70 only)



Index	Explanation	Index	Explanation
1	Diesel engine - M57D30T2	18	Oxidation catalyst and Diesel particle filter (DOC/DPF)
2	Intake silencer (air filter)	19	Exhaust gas temperature sensor - pre catalyst (DOC)
3	HFM	20	Oxygen sensor
4	Compressor bypass valve	21	Wastegate valve
5	Turbocharger - low pressure stage	22	Turbine control valve
6	Turbocharger - high pressure stage	23	Exhaust pressure sensor (after exhaust manifold)
7	Bypass valve for High Pressure EGR cooler	24	Swirl port actuator
8	High-pressure EGR cooler	25	Boost pressure sensor
9	Temperature sensor for high-pressure EGR	26	Exhaust differential pressure sensor
10	High-pressure EGR valve	27	NO_X sensor - pre SCR catalyst
11	Throttle valve	28	Temperature sensor - post DPF
12	Charge air temperature sensor	29	Dosing (metering) module (for SCR system)
13	Intercooler	30	Mixer (for SCR system)
14	Low pressure EGR valve with position sensor	31	SCR Catalyst
15	Temperature sensor for low pressure EGR	32	NO_X sensor - post SCR catalyst
16	Low pressure EGR cooler	33	DDE 7.3
17	Exhaust gas temperature sensor - post catalyst (DOC)	34	Muffler (silencer)

Air Intake Systems

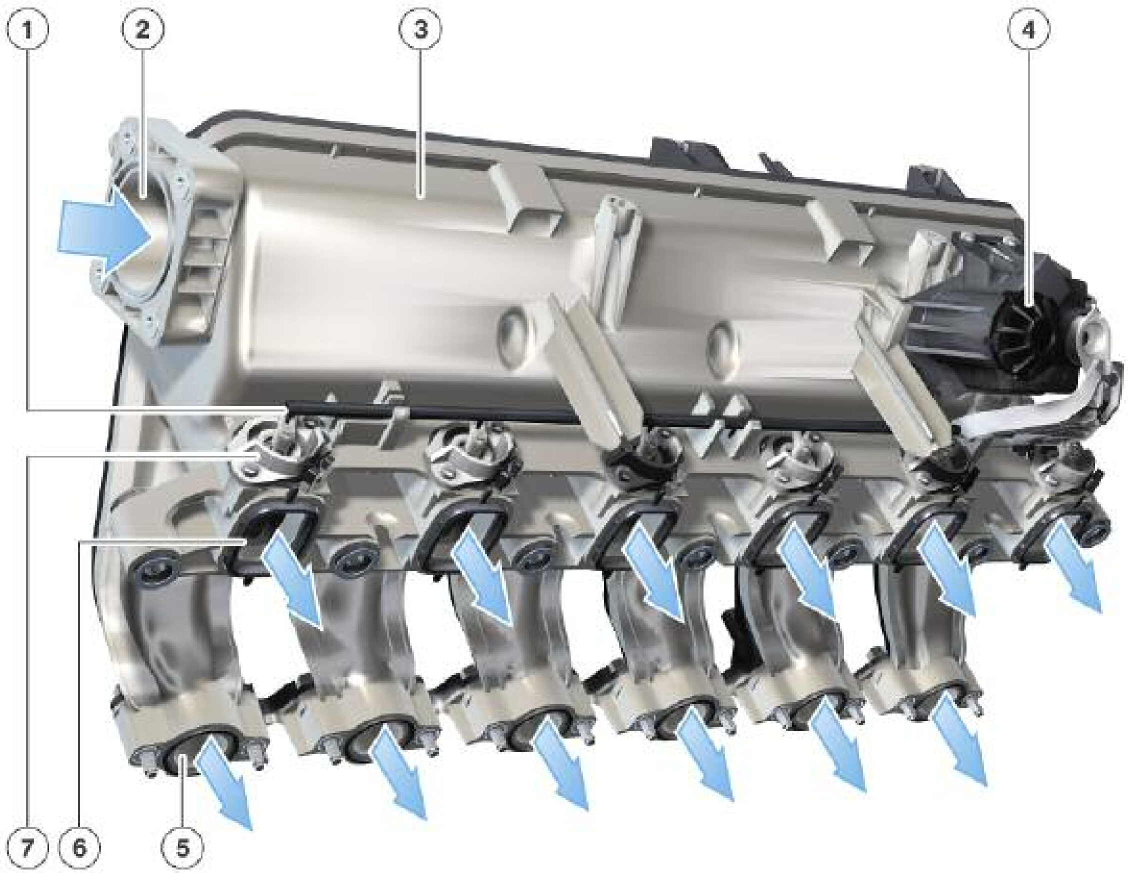
The intake air ductwork differs between the E70 and E90. Both vehicles will draw air from behind the kidney grill. On the E70, the air filter housing and silencer is located on top of the engine. On the other hand, the E90 has a filter housing on the passenger side inner fender.



Index	Explanation	Index	Explanation
A	Air intake system - E70	3	Air filter housing
B	Air intake system - E90	4	HFM
1	Intake air point of entry	5	Fresh (filtered) air intake pipe
2	Unfiltered air intake	6	Blow-by tube

Swirl Flaps

The US version of the M57 engine utilizes the previously known swirl flaps which are located in the intake manifold. The primary difference is that the swirl flaps are now controlled electrically, rather than with vacuum. This method of actuation also provides a means of position feedback with the DDE system to comply with OBD requirements. An additional benefit of this method of control is a more precise positioning of the swirl flaps as needed. The flaps are map controlled using engine speed, engine load and coolant temperature.

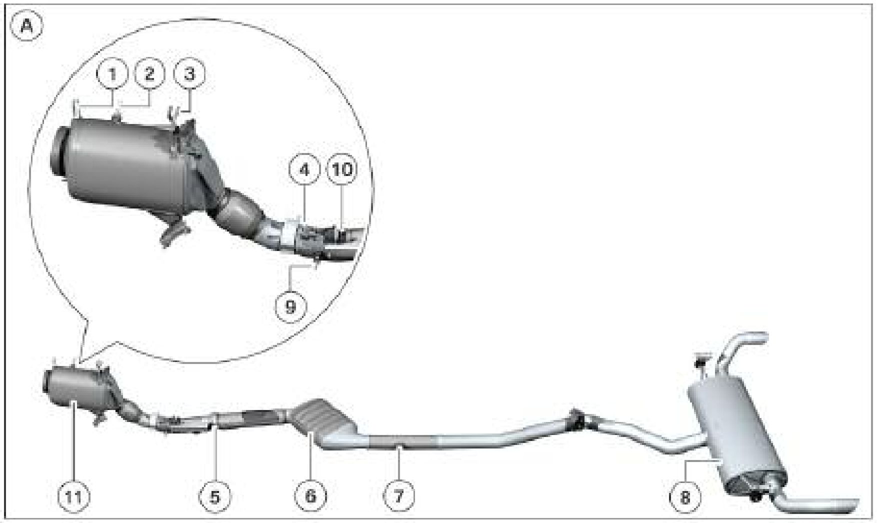


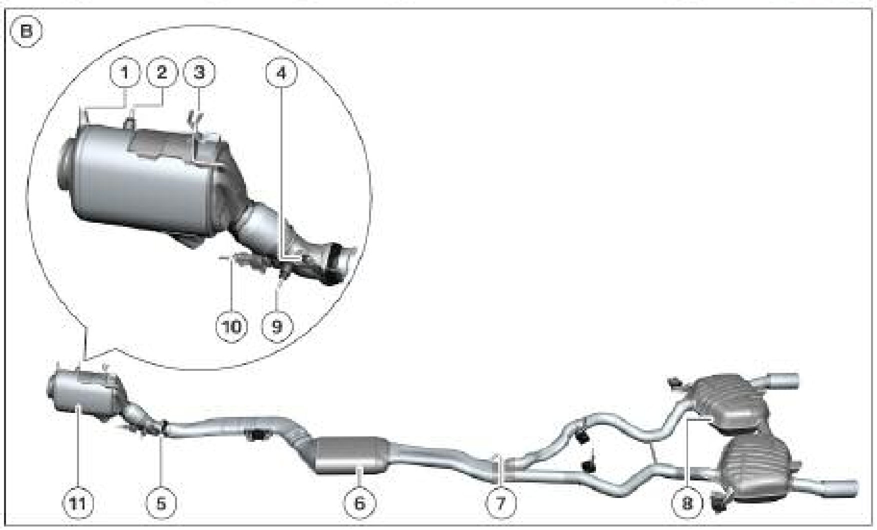
Index	Explanation	Index	Explanation
1	Control rod for swirl flaps	5	Swirl ports
2	Throttle plate mounting	6	Tangential ports
3	Intake manifold	7	Swirl flaps
4	Electric motor (for swirl flaps)		

Exhaust System

The exhaust systems for both the E90 and E70 have been adapted for the US market. There are special provisions for the SCR system as well as for the US specific OBD monitoring of the DOC.

Each system is unique to the vehicle with different muffler and tailpipe features.





Index	Explanation	Index	Explanation
A	Exhaust system E70	6	SCR catalyst
B	Exhaust system E90	7	NO_X sensor after SCR catalyst
1	Oxygen sensor Exhaust gas temperature sensor before DOC (concealed)	8	Rear silencer (muffler)
2	Exhaust gas temperature sensor after DOC	9	Exhaust gas temperature sensor after DPF
3	Differential pressure sensor	10	Metering module
4	NO_X sensor before SCR catalyst	11	Diesel particulate filter (DPF)
5	Mixer		

EGR System

For more information on EGR systems, refer to the section on “Emission Controls”.

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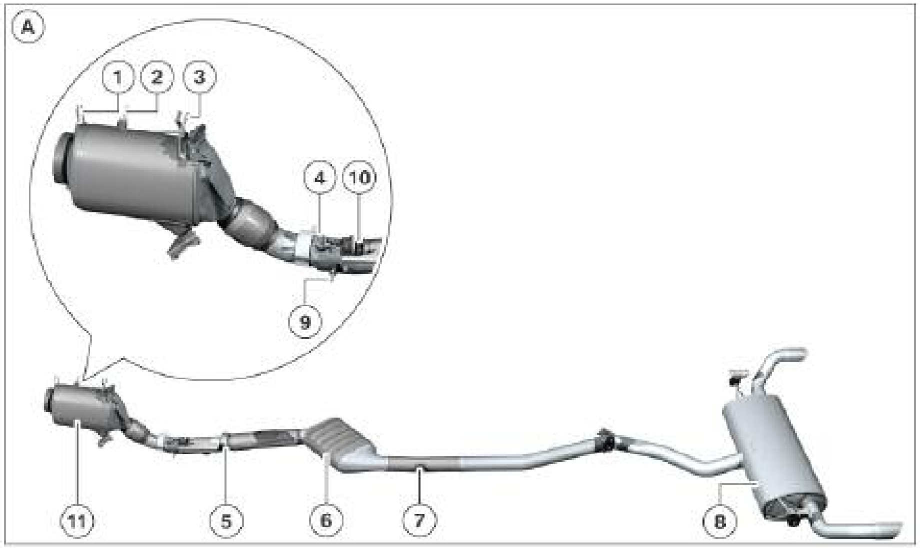
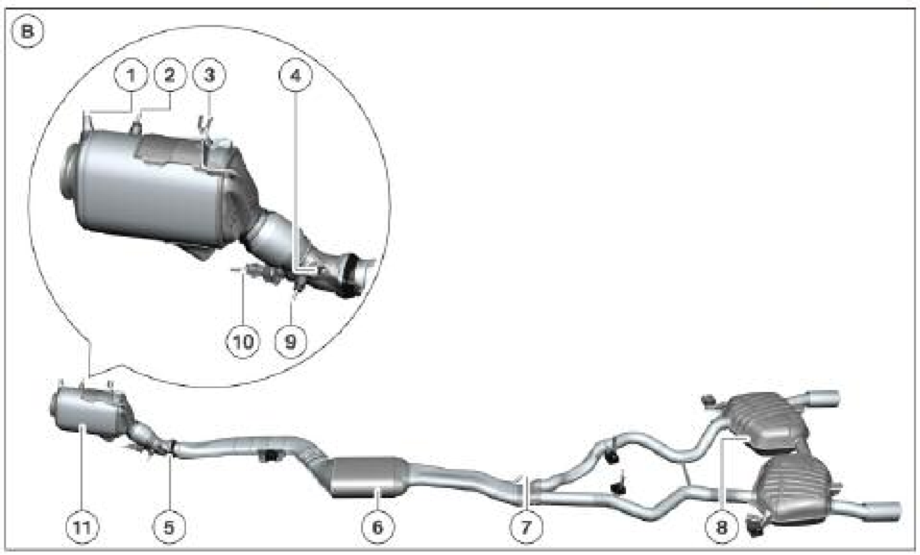
Workshop Exercise - Exhaust System Components

1. Complete exercise by filling in the "function/purpose" of the exhaust system components. Then, locate and identify the exhaust system components on the vehicle:





Index	Explanation	Function/Purpose
A	Exhaust system E70	E70
B	Exhaust system E90	E90
1	Oxygen sensor	
	Exhaust gas temperature sensor before DOC (concealed)	
2	Exhaust gas temperature sensor after DOC	
3	Differential pressure sensor	
4	NO_X sensor before SCR catalyst	
5	Mixer	
6	SCR catalyst	
7	NO_X sensor after SCR catalyst	
8	Rear silencer (muffler)	
9	Exhaust gas temperature sensor after DPF	
10	Metering module	
11	Diesel particulate filter (DPF)	

Workshop Exercise - Exhaust System Components

Using the diagnostic equipment, access the "Service Functions" menu and go to DPF. (Do not start vehicle at this time)

What are the two selections in the DPF menu?

According to the test module, what is the replacement interval of the DPF?

When should the "DPF Regeneration" test module be carried out?

How is the "DPF Regeneration" test module carried out? (i.e. Can it be completed in the shop?)

Go to "Status Requests" under the DPF section and highlight all values. Read out with the engine running.
Fill in chart below with the values:

Status request	Value	Status request	Value
Differential pressure sensor		Consumption per 100km	
Regeneration enabled		Distance remaining on DPF	
Regeneration released		Distance traveled since regeneration	

Classroom Exercise - Review Questions

1. What changes were made to the piston on the US version of the M57D30T2 engine? (circle one)

   The piston pin is larger in diameter

   The piston pin is offset in the piston

   The piston pin is made from a stronger material

   The piston pin is lighter

2. Which of the following statements are ***TRUE*** regarding the driveline changes on the diesel vehicles?
   (circle the true statements, cross out the false statements)

   On the diesel vehicles, the gear ratio in the differential is the same as the gasoline powered vehicles.

   The transmission gear ratios are the same

   The transmission on the diesel vehicles is also used on the 8-cylinder, gasoline powered vehicles

   The torque converter is the same between gasoline and diesel powered vehicles

3. Why is it important to be sure that the air intake system is "oil-free" before starting the engine?

   ____

   ____

   ____

   ____

4. Which of the following engine management components are "electrically actuated" (directly connected) by the DDE?

   (circle those that apply)

Compressor bypass valve	SCR metering valve
Bypass valve for HP-EGR cooler	Wastegate
Throttle valve	Swirl flaps
High pressure EGR valve	Low pressure EGR valve
Turbine control valve	

5. Which of the following engine management components are "vacuum controlled" (via EPDW) by the DDE?

   (circle those that apply)

Compressor bypass valve	SCR metering valve
Bypass valve for HP-EGR cooler	Wastegate
Throttle valve	Swirl flaps
High pressure EGR valve	Low pressure EGR valve
Turbine control valve	

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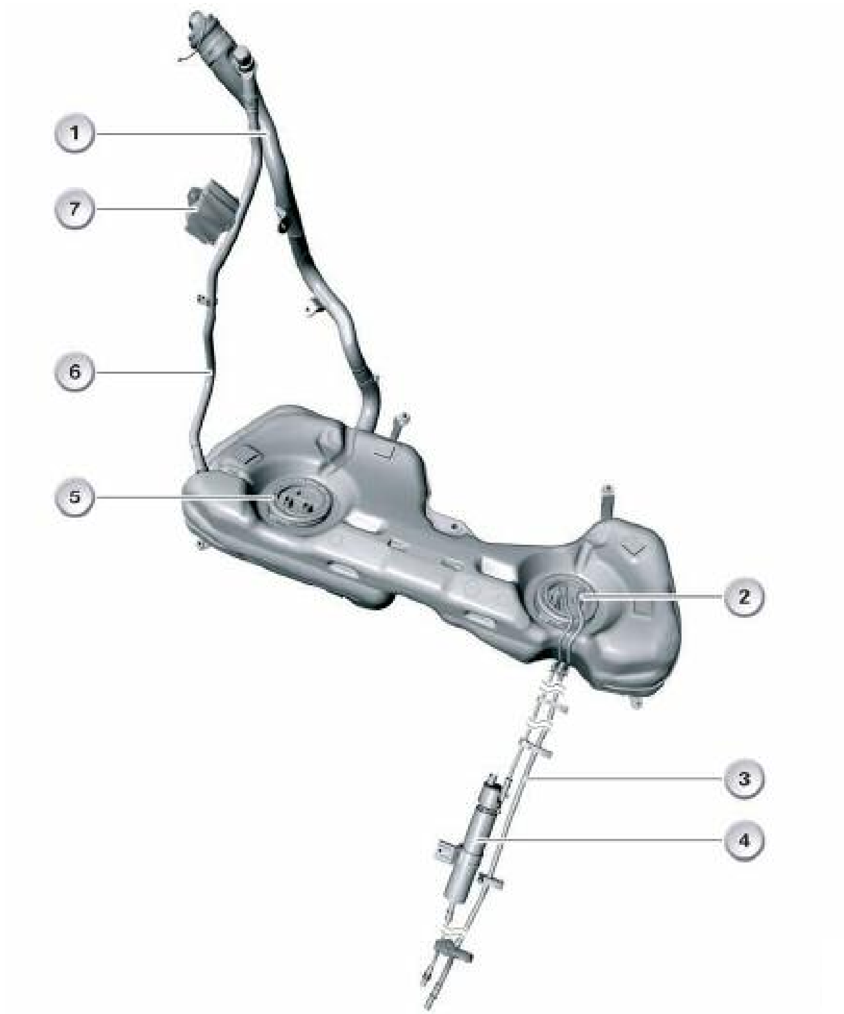
Fuel System

Fuel Supply Overview

As with current gasoline fuel injection systems, there is an electric fuel pump located in the fuel tank. The fuel pump supplies the needed low pressure fuel to feed the mechanical high-pressure pump.



Index	Explanation
1	Fuel filler neck
2	Left hand service opening
3	Fuel return line
4	Fuel filter with heating system
5	Right hand service opening
6	Filler vent
7	Electric fuel pump module (EKP)

The fuel tank is equipped with two chambers and, on modern vehicles, is made from plastic. The electric fuel pump on the diesel engines is driven by the EKP module.

Similar to BMW gasoline engines, the fuel system on the vehicles equipped with diesel engines share much of the same “low pressure” system components.

However, there are some distinct differences with the diesel engine.

These are:

- The system includes a fuel return line
- The breather system is significantly simpler
- There is no carbon canister (AKF) and no fuel tank leakage diagnosis module (DMTL)
- There is no pressure regulator
- The fuel filter is not located in the fuel tank.

The design layout of the fuel supply systems in the E70 and E90 are described in the following.

Fuel Tank

As with all modern BMW vehicles, the fuel tank is made from plastic and is installed in the optimum position to achieve the best possible weight balance in the vehicle.

To accommodate these needs, the fuel tanks must be designed in such a way so that there is room for the driveshaft to pass through with out interference.

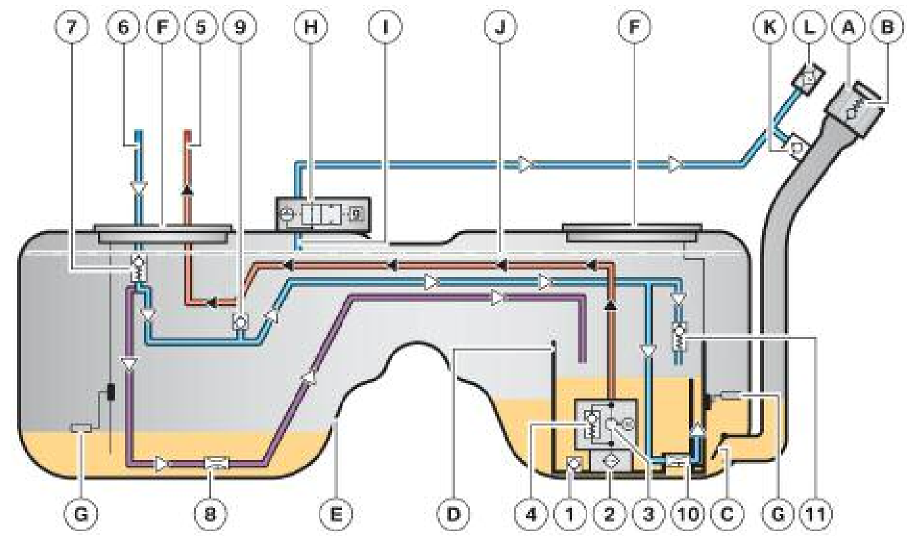
So, the fuel tanks in the diesel vehicles feature the familiar "double-chamber" configuration. This design feature accommodates two delivery units which are located in the right and left fuel tank halves.

The fuel pump (3) with intake filter (2) is a part of the right-hand delivery unit. The surge chamber including a suction jet pump (10) with pressure relief valve (11) and initial fill valve (1) as well as a lever-type sensor (G) complete this delivery unit.

The suction jet pump (8), lever-type sensor (G), leak prevention valve (7) and air inlet valve (9) belong to the left-hand delivery unit.

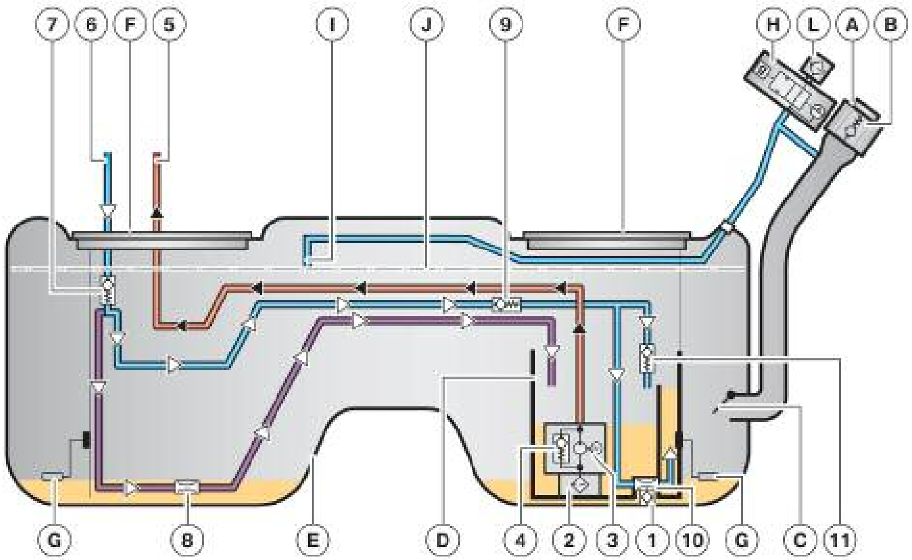
A line leads from the filler vent valve (H) to the filter (L). The fuel filler pipe is connected to this line via the non-return valve (K).

E70 Fuel Tank



Index	Explanation	Index	Explanation
A	Fuel filler cap	1	Initial fill valve
B	Pressure relief valve	2	Intake mesh filter
C	Non-return valve	3	Fuel pump
D	Surge chamber	4	Pressure relief valve
E	Fuel tank	5	Feed line
F	Service cap	6	Return line
G	Lever-type sensor	7	Leak prevention valve
H	Filler vent valve	8	Suction jet pump
I	Connection	9	Air inlet valve
J	Maximum fill level	10	Suction jet pump
K	Non-return valve	11	Pressure relief valve
L	Filter		

E90 Fuel Tank

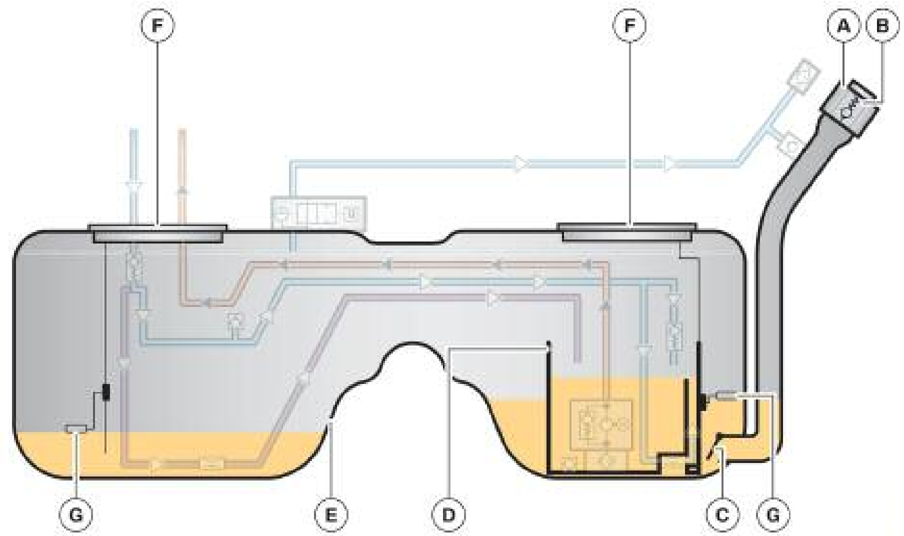


Index	Explanation	Index	Explanation
A	Fuel filler cap	1	Initial fill valve
B	Pressure relief valve	2	Intake mesh filter
C	Non-return valve	3	Fuel pump
D	Surge chamber	4	Pressure relief valve
E	Fuel tank	5	Feed line
F	Service cap	6	Return line
G	Lever-type sensor	7	Leak prevention valve
H	Filler vent valve	8	Suction jet pump
I	Connection	9	Air inlet valve (check valve)
J	Maximum fill level	10	Suction jet pump
L	Filter	11	Pressure relief valve

Fuel Tank Functions

A pressure relief valve (B) is integrated in the fuel filler cap (A) to protect the fuel tank (E) from excess pressure. A non-return flap (C) is located at the end of the fuel filler neck.

The non-return flap prevents the fuel from sloshing back into the fuel filler neck. The components in the fuel tank can be reached via the two service caps (F). The fuel fill level can be determined via the two lever-type sensors (G). The surge chamber (D) ensures that the fuel pump always has enough fuel available for delivery.

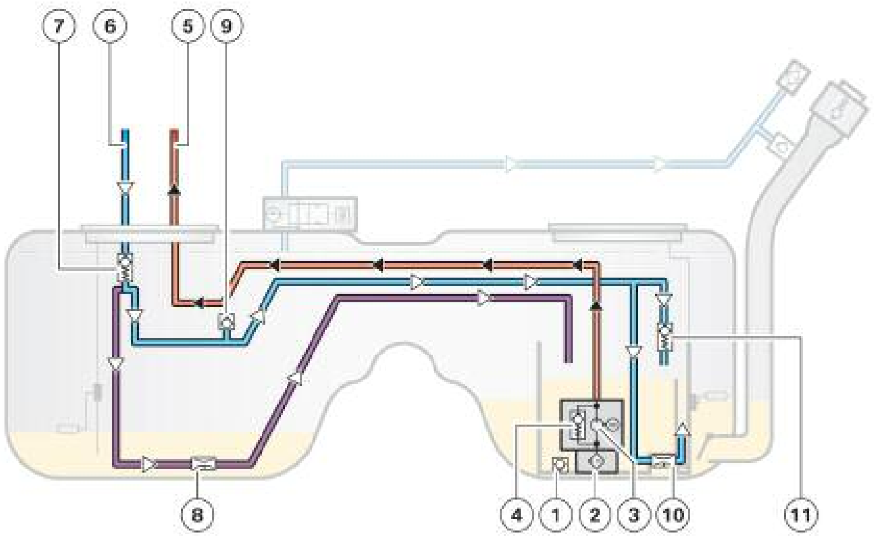


Index	Explanation	Index	Explanation
A	Fuel filler cap	E	Fuel tank
B	Pressure relief valve	F	Service cap
C	Non-return valve	G	Lever-type sensors
D	Surge chamber		

Fuel Delivery from Fuel Tank

In the event of the surge chamber being completely empty, the initial filling valve (1) ensures that fuel enters the surge chamber while refuelling.

The fuel reaches the fuel pump (3) via the intake filter (2), then continues through the delivery line (5) to the fuel filter. The fuel pump is located in the surge chamber. A pressure relief valve (4) is integrated in the fuel pump to prevent pressure in the delivery line from rising too high.



Index	Explanation	Index	Explanation
1	Initial fill valve	7	Leak prevention valve
2	Intake mesh filter	8	Suction jet pump
3	Fuel pump	9	Air inlet valve
4	Pressure relief valve	10	Suction jet pump
5	Feed line	11	Pressure relief valve
6	Return line		

As the engine switches off, the delivery line is depressurized but cannot run dry because, provided the system is not leaking, no air is able to enter it. In addition, after the fuel pump has switched off, the fuel pressure/temperature sensor is checked for plausibility.

Fuel that is required for lubrication and the function of high pressure generation flows back into the fuel tank via the return line (7). The fuel coming from the return line is divided into two lines downstream of the leak prevention valve (7). The non-return valve prevents the fuel tank from draining in the event of damage to lines on the engine or underbody. It also prevents the return line from running dry while the engine is off.

One of the lines guides the fuel into the surge chamber via a suction jet pump (10). The suction jet pump transports the fuel from the fuel tank into the surge chamber. If the fuel delivery pressure in the return line increases too much, the pressure relief valve (11) opens and allows the fuel to flow directly into the surge chamber.

An air inlet valve is used in the E70. The air inlet valve (9) ensures that air can enter the line when the engine is off, preventing fuel from flowing back from the right-hand half of the fuel tank to the left.

Instead of the air inlet valve (9) a non-return valve is used on the E90. The non-return valve ensures that, while the engine is off, fuel from the right-hand half of the fuel tank cannot flow back into the left-hand half. The return system remains completely filled with fuel.

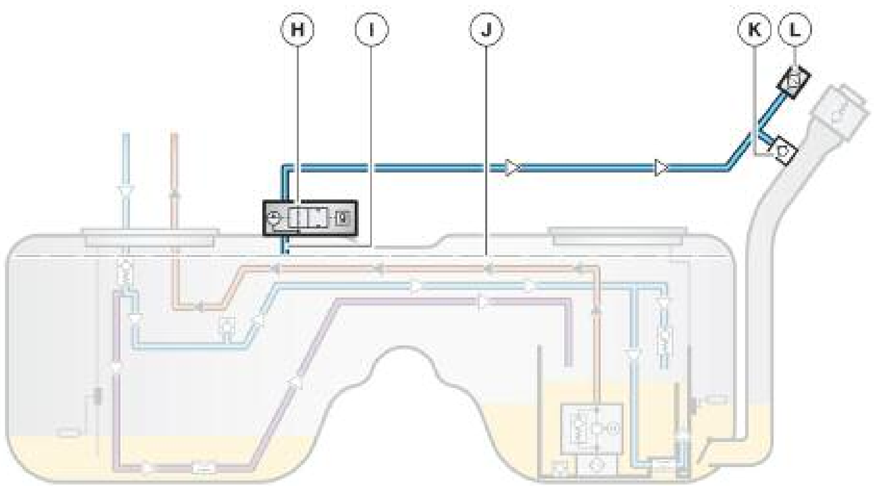
A further line branches off into the left-hand half of the fuel tank after the non-return valve (7) and transports the fuel into the surge chamber via the suction jet pump (8).

Air Supply and Extraction

Fuel ventilation is ensured by means of the filler vent valve (H). The filler vent valve is located in the fuel tank and uses the connection (I) to determine the maximum fill level (J). The filler vent valve contains a float that buoys upwards on the fuel when the vehicle is refuelled and blocks the filler ventilation. The fuel rises in the fuel filler and the fuel nozzle switches off.

A roll-over valve is also integrated in the filler vent valve to block the ventilation line when a certain angle of incline is reached and prevents fuel from draining out if the vehicle were to roll over.

The non-return valve (K) prevents fuel from escaping via the ventilation when the vehicle is refuelled. During operation, air can flow into the fuel filler pipe and the fuel can flow from the fuel filler pipe into the tank.



Index	Explanation	Index	Explanation
H	Filler vent valve	K	Non-return valve
I	Connection	L	Filter
J	Maximum fill level		

The filter (L) prevents dirt or insects from entering the ventilation and blocking the line.

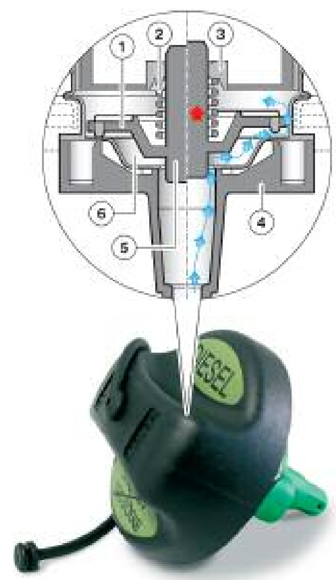
If the ventilation line does become blocked, fuel consumption during operation would cause negative pressure and the fuel tank would be compressed and damaged.

Fuel Filler Cap

The fuel filler cap contains a pressure relief valve to ensure that, if there is a problem with fuel tank ventilation, any excess pressure that may form can escape and the fuel tank is not damaged.

If excess pressure forms in the fuel tank, this causes the valve head (1) and with it the entire pressure relief valve (5) to be lifted off the sealed housing (6). The excess pressure can now escape into the atmosphere. The excess pressure spring (2) determines the opening pressure.

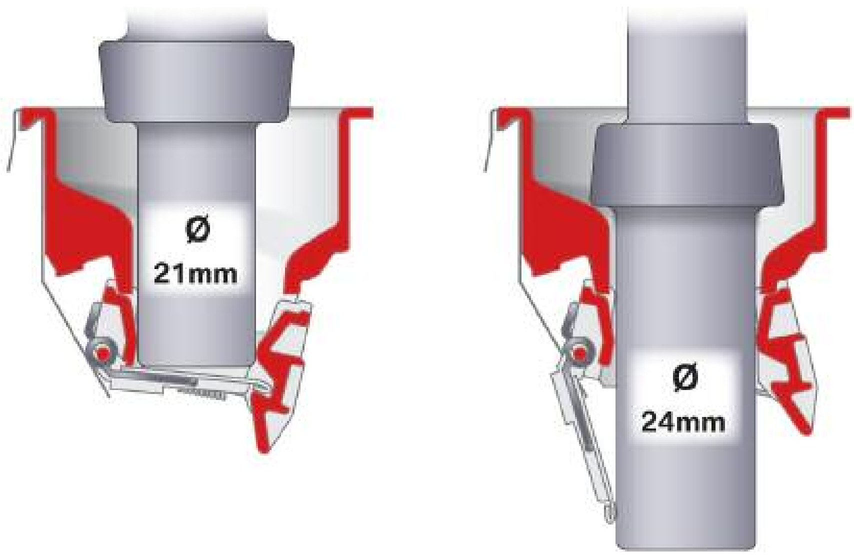
The excess pressure spring uses a defined pressure to push the pressure relief valve onto the sealed housing and is supported by the brace (3).

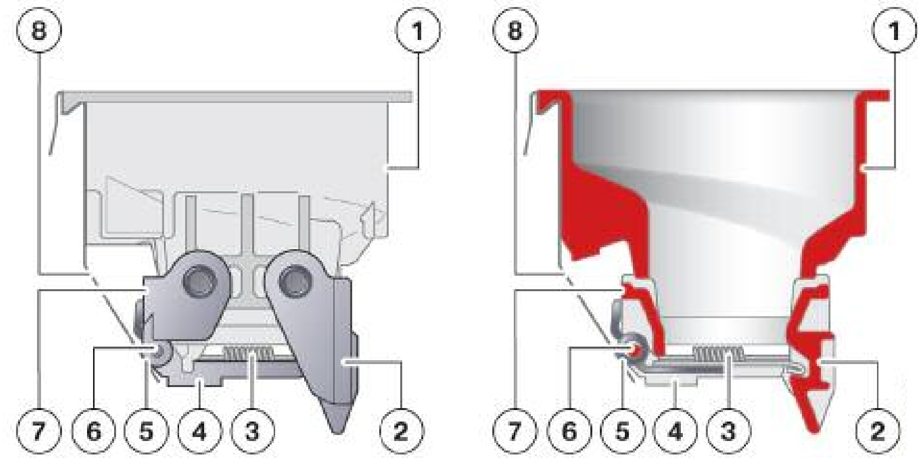


Index	Explanation
1	Valve head
2	Excess spring pressure
3	Brace
4	Bottom section of housing
5	Pressure relief valve
6	Sealed housing

Misfueling Protection

A mechanical system has been developed in order to help prevent a mis-fueling situation. To make sure that the diesel vehicles are only refueled with the proper diesel fuel, a mechanical flap has been added to the fuel filler neck.





Index	Explanation	Index	Explanation
1	Housing	5	Torsion spring
2	Locking lever	6	Rivet
3	Tension spring	7	Hinged lever
4	Flap	8	Ground strap

As the following illustrations show, only a fuel nozzle with a diameter of approximately 24 mm can fit. If the diameter is approximately 21 mm, the flap (4) does not open as the hinged lever (7) and the locking lever (2) cannot be pushed apart.

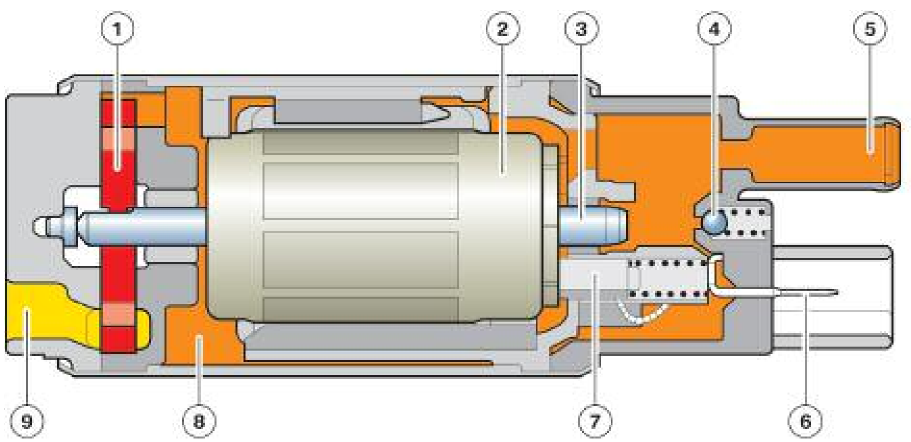
If a diesel fuel nozzle is inserted, this pushes the locking lever (2) and the hinged lever (7) at the same time. The hinged lever is pushed outwards against the tension spring (3) and releases the flap (4). This is only possible, however, if the hinged lever cannot move freely and is also locked in position by the fuel nozzle.

To open the protection against incorrect refuelling feature in the workshop, a special tool is required.

Fuel Pump

Today's diesel vehicles are fitted with electric fuel pumps to deliver the needed fuel to the high pressure pump. The electric fuel pump is designed to deliver a sufficient amount of fuel to lubricate and cool the injectors and the high-pressure pump and to satisfy the maximum fuel consumption of the engine.

It has to deliver the fuel at a defined pressure. That means that when the engine is idling or running at medium power, the fuel pump delivers several times more than the amount of fuel required. The fuel pump delivers approximately three or four times the volume of maximum possible fuel consumption.



Index	Explanation	Index	Explanation
1	Impeller	6	Electrical connection
2	Driveshaft	7	Sliding contacts
3	Electric motor	8	Pressure chamber
4	Pressure relief valve	9	Intake section
5	Pressure connection		

The electric fuel pump is located in the fuel tank. There it is well protected against corrosion and the pump noise is adequately soundproofed.

The fuel pump on BMW diesel engines may either be a gear pump, a roller-cell pump or a screw-spindle pump. The following fuel pumps are used on USA vehicles:

- E70 - Screw spindle pump
- E90 - Gear pump (rotor type)

The operating principle of each of these types of pump is described below. The pump itself is driven by the drive shaft (2) of the electric motor (3). The electric motor is controlled by the electrical connection (6) and sliding contacts (7).

Passing first through the intake filter and then the remainder of the intake section (9), the fuel enters the impeller (1). The fuel is pumped through pressure chamber (8) on the electric motor, past the pressure connection (5) and onwards to the fuel filter and engine.

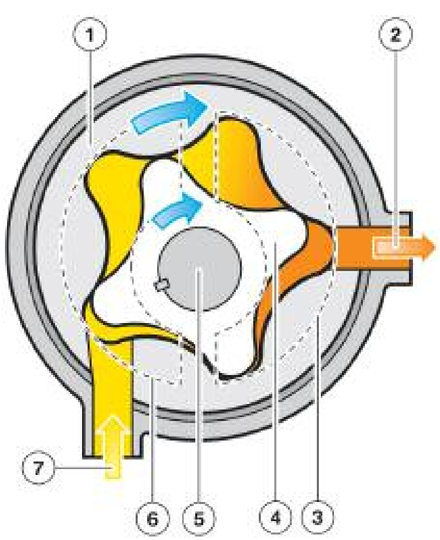
If the fuel delivery pressure increases to an impermissible value, the pressure relief valve (4) opens and allows the fuel to flow into the surge chamber.

Fuel Pump - E90

On the E90, the fuel pump is a gear type pump. The gear pump is comprised of an outer rotor (1) with teeth on the inside, and an inner rotor (4) with teeth on the outside. The inner rotor is driven by the drive shaft (5) of the electric motor. The outer rotor is propelled by the teeth of the inner rotor and thus turns inside the pump housing.

The inner rotor has one tooth fewer than the outer rotor, which means that, with each revolution, fuel is carried into the next tooth gap of the outer rotor.

During the rotary motion, the spaces on the intake side enlarge, while those on the pressure side become proportionately smaller. The fuel is fed into the rotor pump through two grooves in the housing, one on the intake side and one on the pressure side. Together with the tooth gaps, these grooves form the intake section (6) and pressure section (3).

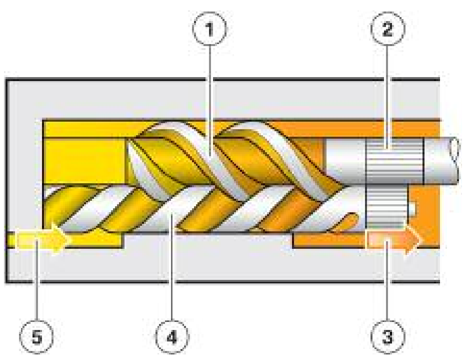


Index	Explanation
1	Outer rotor
2	Fuel delivery to engine
3	Pressure section
4	Inner rotor
5	Driveshaft
6	Intake section
7	Fuel from tank

Screw-spindle Pump - E70

With the screw-spindle pump, two screw spindles intermesh in such a way that the flanks form a seal with each other and the housing. In the displacement chambers between the housing and the spindles, the fuel is pushed towards the pressure side with practically no pulsation.

In this way, the screw spindles pump fuel away from the fuel tank (5). The fuel is then fed to the engine (3) through the pump housing and the fuel delivery line.



Index	Explanation
1	Driveshaft screw spindle
2	Gearwheel
3	Fuel delivery to the engine
4	Screw spindle
5	Fuel from tank

Low Pressure Fuel System - E90

The low pressure fuel systems differ between the E70 and E90. The E90 is a “speed regulated” system which means that the fuel pump speed is regulated by the EKP module based on request from the DDE.

The fuel pump will be activated with the “ignition on” signal. If the engine is not started, the fuel pump will be switched off after a defined time period. When the engine is switched off, the fuel pump is switched off as well.

Fuel Temperature Sensor

The fuel temperature sensor is located in the fuel feed line just before the high pressure pump.

The sensor consists of a temperature dependent resistor with which works on the NTC principle.

The fuel temperature sensor registers the fuel temperature just before the high pressure pump. The fuel temperature sensor is installed on the low pressure side of the fuel system.

Fuel temperature sensor - E90

The density of the fuel changes as temperature changes. The DDE requires the fuel temperature for the purpose of precisely calculating the start of injection and injection quantity.

The fuel temperature sensor consists of a temperature-dependent measuring resistor made from semiconductor material that is integrated in a housing. The measuring resistor has a negative temperature coefficient (NTC).

The digital diesel electronics compares the measured voltage with a characteristic curve that assigns a corresponding temperature to each voltage value.

The various sensors and actuators are required for ensuring effective operation of the fuel system and engine. Apart from ensuring compliance with legal requirements, these components are also responsible for providing outstanding engine performance and the associated acoustics.

Fuel Filter Heating - E90

On the E90, the fuel filter heater is not controlled directly by the DDE. A pressure switch and a temperature sensor are located in the fuel filter housing.

The fuel heater only works with the ignition switched on and when both of the following conditions are fulfilled:

- Temperature drops below a defined value
- A defined fuel delivery pressure is exceeded due to cold, viscous fuel.

If the filter is clogged, a corresponding signal is sent via a diagnosis line to the DDE. This is the case when, despite a sufficiently high temperature, the fuel pressure upstream of the filter does not drop.

The conditions for fuel filter heater operation are as follows:

- The fuel heater is is switched ON when - the fuel pressure is greater than 6 bar AND the fuel temperature is less than 2°C.
- The fuel heater is switched off when - the fuel pressure is less than 5.5 bar for a duration of greater than 5 minutes OR
- the fuel temperature is greater than 12°C OR
- during the starting process if the electronics in the fuel filter detect a battery voltage of less than 7.5 V for longer than 0.2 seconds.

The fuel heater is not activated by the DDE control module. However, the fuel heater reports a detected filter blockage via the signal DIAG_DKH to the DDE control module. The DDE control module then stores the fault.

Low Pressure Fuel System - E70

The low pressure fuel system on the E70 is a “pressure regulated” system which uses the signal from the fuel pressure sensor located in the low pressure fuel line.

The fuel pump operates with "ignition ON". If the engine is not started, the fuel is switched off at a specific pressure. When the engine is running, the fuel pump is regulated on-demand by the EKP module in response to a load signal from the DDE in order to ensure a uniform fuel pressure at the inlet to the high-pressure pump.

The functions of the low pressure fuel system are integrated into the DDE control module. The DDE uses the pressure information from the combined fuel pressure-temperature sensor to determine the current actual pressure in the low pressure system.

In order to maintain the approximate delivery pressure of 4.8 to 5.0 bar, the DDE uses a number of input variables. The input variables relevant to determining the adjusting value are:

- Actual pressure in the pre-supply system
- Engine speed
- Injection volume

The adjusting value is sent from the DDE to the EKP module in the form of a CAN message.

Fuel Pressure-temperature Sensor

The fuel pressure-temperature sensor consists of two independent sensors combined in one housing.

The fuel temperature sensor is required to precisely calculate the start of injection and injection quantity. The fuel pressure sensor registers the fuel pressure upstream of the high pressure pump. This fuel pressure is required for the purpose of controlling the fuel pump in the fuel tank.

The fuel pump is also switched off when the engine is turned off and the fuel feed is depressurized. After the fuel pump has been shut down, the digital diesel electronics checks and evaluates the plausibility of the fuel pressure sensor. If a fault is detected, the corresponding fault code is stored in the fault code memory of the digital diesel electronics.

The integrated fuel temperature sensor is identical to the fuel temperature sensor used in the E90. The fuel pressure sensor is also integrated in the housing. Both the fuel pressure sensor and the fuel temperature sensor features two separate connections in a common connector housing that has four pins.

The fuel pressure sensor consists of resistors mounted on a diaphragm. The one side of the diaphragm has contact with the fuel so that the fuel pressure acts on the diaphragm.

The greater the pressure, the more the diaphragm is deflected. The resistors on the diaphragm change their resistance in response to the mechanical stress. A bridge circuit and electronic signal processing circuitry in the sensor amplify the bridge voltage, compensate for temperature influences and linearize the pressure characteristic curve.

The output voltage for the digital diesel electronics is in the range between 0 and 5 volts. As for the temperature sensor, a characteristic curve is stored in the digital diesel electronics that assigns a corresponding pressure to each voltage value.

Fuel Filter Heating - E70

The fuel filter heating operation is somewhat different in the E70. The E70 has a pressure-controlled fuel supply system. In this system, the fuel filter heater is actuated by the DDE. The DDE communicates with the filter heater via the signal S_KSH.

A combined fuel pressure and temperature sensor upstream of the high pressure pump is used. If required, the fuel filter is heated with an electrical heating element. The DDE switches the fuel filter heating on under the following conditions:

- Temperature drops below a defined value
- The required fuel pressure is not reached despite increased power intake of the electric fuel pump.

The DDE recognizes a clogged filter when the target pressure upstream of the high pressure pump is not reached despite a sufficiently high fuel temperature and high current consumption of the electric fuel pump.

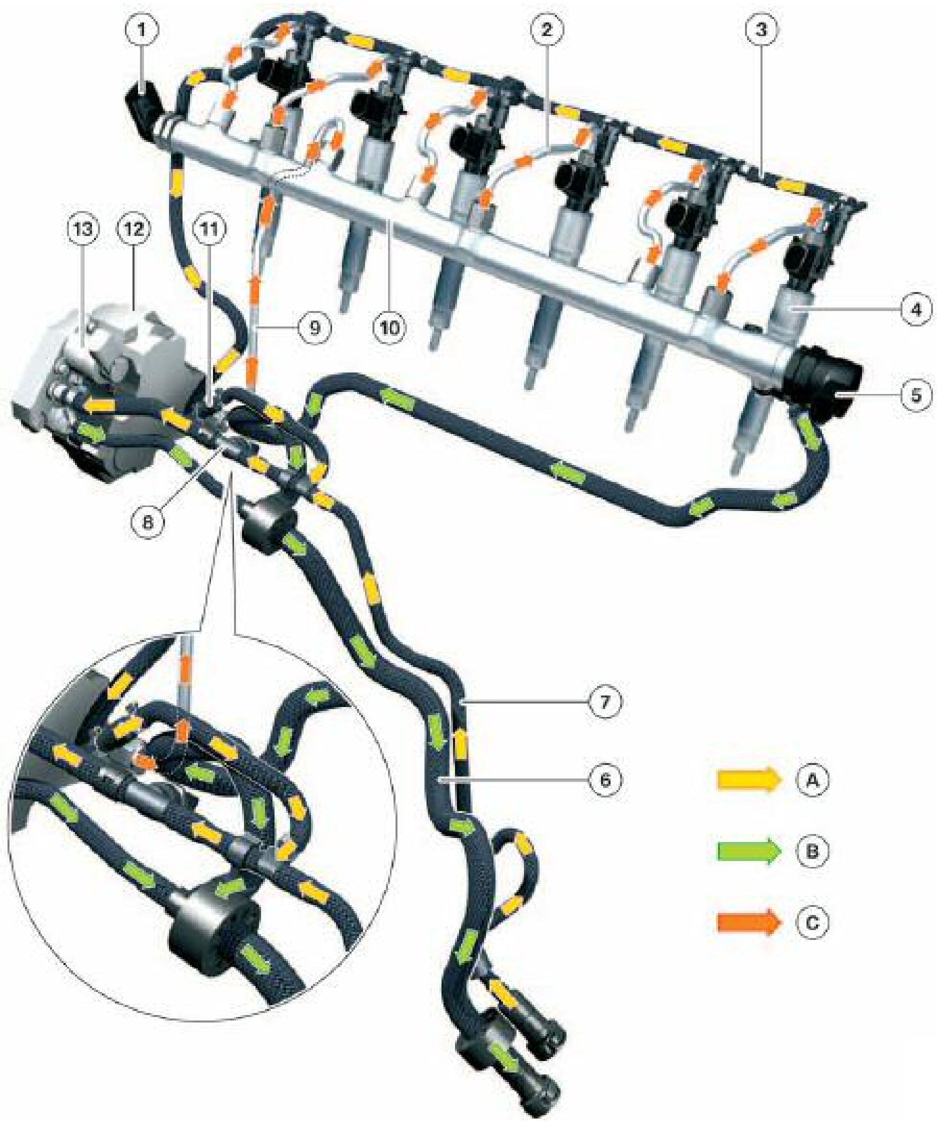
The electrical power output of the fuel pump is higher than the stored adaptation value ”electric fuel pump” plus an offset for more than 3 seconds. The offset is determined from a characteristic map and depends on the engine speed and fuel injection rate.

The fuel filter heating is switched off again under the following conditions:

- Activation time > 5 min or
- Fuel temperature > 8°C or
- Battery voltage is less than 9 volts for more than 30 seconds

High Pressure Fuel System

The high pressure fuel system is mostly identical in design and function as compared to the European version. However, some components have been adapted to the different fuel specification.



Index	Explanation	Index	Explanation
A	Fuel feed (low pressure)	6	Return line
B	Fuel return	7	Feed line
C	Fuel high pressure	8	Fuel temperature (or temp/pressure)
1	Fuel rail pressure sensor	9	High pressure line
2	High pressure line	10	Fuel rail
3	Leakage line	11	Restrictor
4	Piezo injector	12	High pressure pump
5	Fuel rail pressure control valve	13	Volume control valve

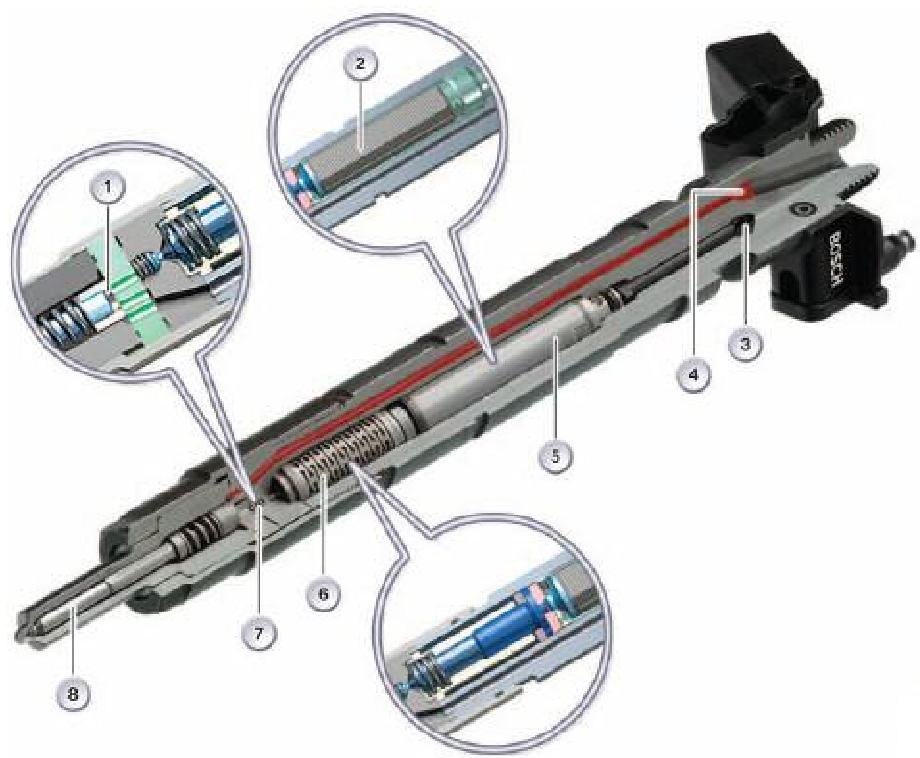
These components are:

- High-pressure pump
- Fuel rail
- Fuel injectors.

These adaptations are restricted to different coatings and materials on the inside.

Fuel Injectors

Compared to a piezo fuel injector on a gasoline engine, the diesel injector operates quite differently. The concept of piezo electricity is the same, but applied in a different manner.



Index	Explanation	Index	Explanation
1	Control chamber	5	Actuator module
2	Piezo element	6	Coupler module
3	High pressure supply	7	Relay valve
4	Supply duct to the nozzle	8	Nozzle needle

On a gasoline engine, the piezo element is used to physically operate the injector pintle in an outward motion. Due to the very high pressures used in a diesel engine, the piezo element cannot be used to directly actuate the pintle. The pintle on a diesel fuel injector moves inward (away from the combustion chamber).

Instead, the piezo element is used to trigger a relay valve in the actuator module. The injector is then hydraulically “imbalanced” which causes the pintle to open via the fuel rail pressure.

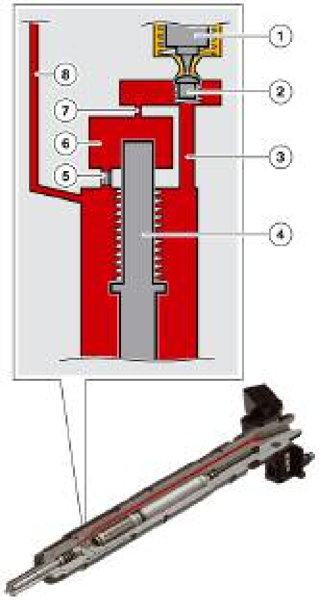
The piezo-element (2) is located inside the actuator module (5). When controlled, it produces the movement necessary to open the relay valve.

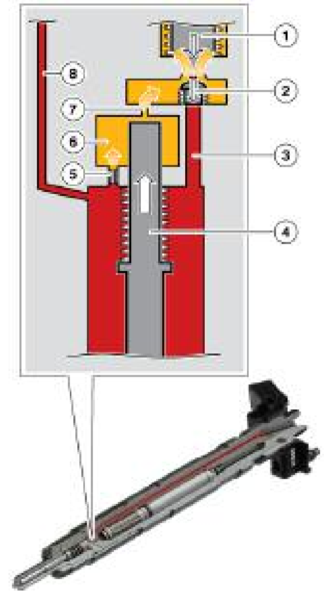
Circuited between the two elements is the coupler module (6), which functions as a hydraulic compensating element, e.g. to compensate for temperature-related length expansions.

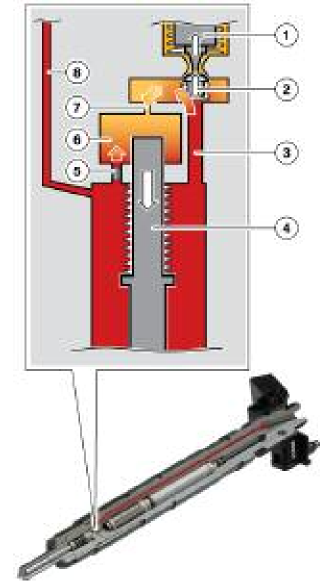
When the fuel injector is controlled, the actuator module expands. This movement is transferred to the relay valve (7) by the coupler module. When the relay valve opens, the pressure in the control chamber (1) drops and the nozzle needle opens.

The benefits of the piezo-fuel injector are that they offer a considerably faster control response, which results in greater metering accuracy. In addition, the piezo-fuel injector is smaller, lighter and has a lower power consumption.

Piezo Injector Operation







Index	Explanation
1	Coupler module
2	Control valve
3	Bypass
4	Nozzle needle
5	Restrictor
6	Control volume
7	Outlet
8	Supply duct to nozzle

Injector Opening

If the fuel injector is activated by the DDE, the piezo-element presses the control valve (2) down against the spring force via the coupler module (1) and closes the bypass (3). The fuel from the control volume (6) can then flow across the outlet (7) and the control valve.

The pressure in the control volume drops and the nozzle needle (4) is opened by the fuel delivery pressure.

Injector Closing

If the injector current feed is set by the DDE, the piezo-element contracts and the coupler module is pressed back by the spring force.

The spring in the control valve closes the valve and clears the bypass. Fuel now reaches the control volume via the bypass, outlet (7) and restrictor (5) and presses the nozzle needle down. The injector is closed and injection is finished.

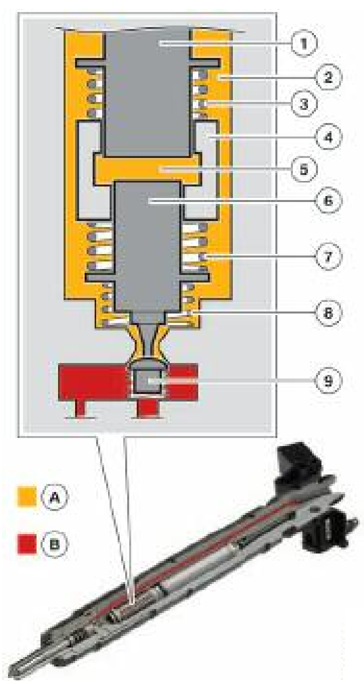
Coupler Module

The hydraulic coupler is surrounded by diesel fuel at a pressure of approximately 10 bar. The piezo-element acts on the upper plunger (1).

Lower plunger (6) rests on control valve (9). The force of spring (7) and of spring (8) is set in such a way that, when closed, the piezo element and control valve (9) are connected free of play via the coupler module.

The upper plunger (1) presses against coupler chamber (5) when the piezo-element is activated.

The force of the piezo-element is increased since plunger (1) has a larger diameter than plunger (6). Plunger (6) opens the control valve (9). When the coupler chamber is pressurized during activation, a small leakage quantity escapes via the clearance in the plunger guide into fuel return (2).



Index	Explanation
A	Fuel feed
B	High pressure fuel
1	Plunger
2	Fuel return
3	Spring
4	Coupler
5	Coupler chamber
6	Plunger
7	Spring
8	Spring
9	Control valve

After injection or after the piezo-element has been switched off, the springs (7 and 8) balance out the play created by the leakage quantity and fuel is again drawn via the clearance in the piston guide into the coupler chamber. This balancing out process takes place so fast that the coupler chamber is completely filled again by the next injection cycle.

A return pressure of approximately 10 bar is required for this purpose, which is achieved by the restrictor in the fuel return of the fuel injectors. The control valve is not operated and no fuel is injected when no pressure is applied in the fuel feed.

Leakage Oil

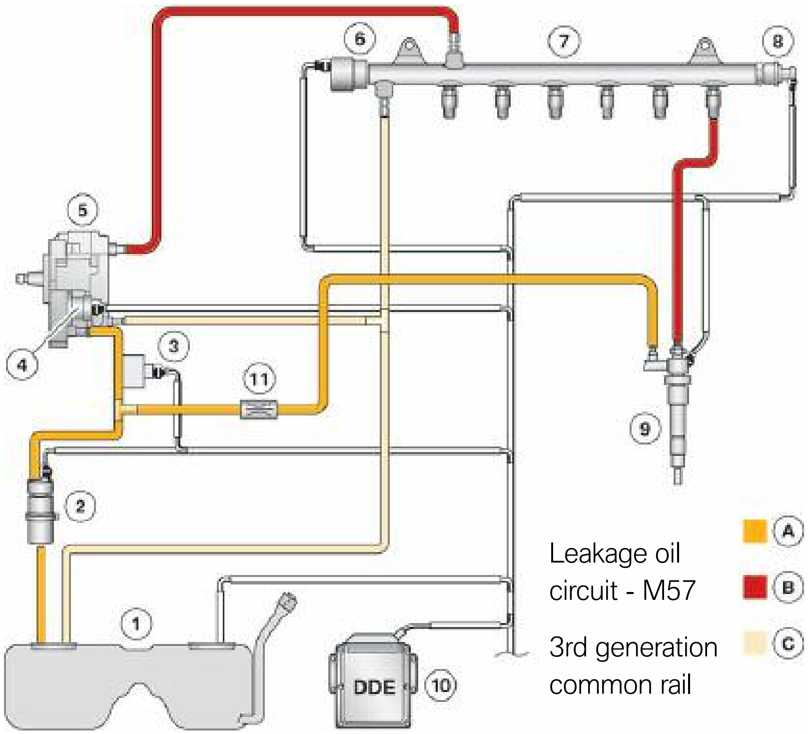
The piezo injectors require a certain amount of backpressure in the leakage circuit in order to operate properly. So, the leakage circuit on the 3rd generation common rail differs from the earlier versions.

In past versions (such as 1st and 2nd generation common rail), the leakage oil circuit drained into the fuel return line.

However, since the piezo injectors operate differently than the earlier solenoid valve injectors, the leakage circuit has been redesigned.

A certain amount of leakage oil occurs in the diesel fuel injectors due to the design of the system. The reason for this is that the relay valve in the piezo-fuel injector needs a certain back pressure to work correctly. The relay valve requires about 10 bar to be present in the leakage circuit to prevent injector malfunctions.

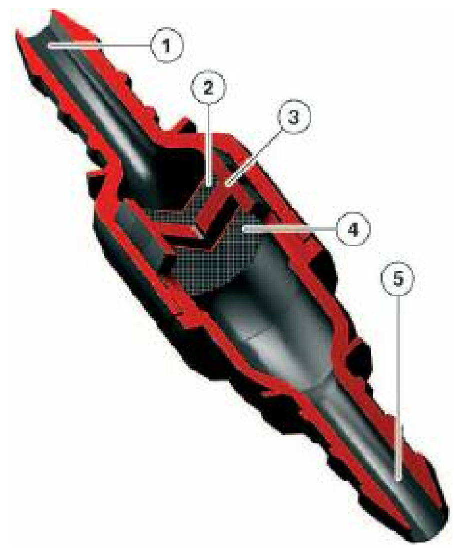
In order to maintain this pressure, a restrictor (11) has been installed between the injector(s) and the low pressure feed to the HP pump.



Index	Explanation	Index	Explanation
A	Fuel feed	5	High pressure pump
B	Fuel high pressure	6	Rail pressure control valve
C	Fuel return	7	Fuel rail
1	Fuel tank	8	Fuel pressure sensor
2	Fuel filter and filter heating	9	Piezo fuel injector
3	Fuel temp (and pressure) sensor	10	DDE
4	Volume control valve	11	Fuel restrictor

Restrictor

The restrictor has a .2 mm orifice which increases the pressure in the fuel return of the fuel injectors. The operating pressure in the leakage oil circuit is about 10 bar.



Index	Explanation
1	Connection from injector leakage line
2	Filter
3	Restrictor (.2mm)
4	Filter
5	Connection to low pressure line

The fuel flowing from the piezo-fuel injectors via the fuel return connection (1) initially passes through a filter (2), through restrictor (3) and then through a further filter (4) to connection (5) back into the fuel feed to the high pressure pump.

There is a filter (2 and 4) on either side of restrictor (3) as the restrictor has no specific direction of flow. The filters ensure that the actual restrictor (3) does not become clogged.

Fuel Injector Volume Adjustment

Piezo-fuel injectors not only bear the hydraulic tolerances but also information concerning the stroke characteristics of the injector. This is a separate classification for the injector voltage calibration.

This information is necessary due to the individual voltage requirement of each fuel injector. The fuel injector is assigned to a voltage requirement class. This replaces the seventh digit of the numerical combination on the injector for hydraulic adjustment.

A piezo-fuel injector therefore has only six characters for the hydraulic adjustment (due to a more precise manufacture of the piezo-fuel injectors) and a seventh character for the injector voltage adjustment.

Index	Explanation
1	7 Character code for adjustment
2	Voltage adjustment

Volume Adjustment

If the digital diesel electronics detects engine speed fluctuations, the actuation period of the fuel injectors is corrected based on these engine speed fluctuations. The volume adjustment adapts the injected volume of all cylinders with respect to each other.

Zero Volume Adaptation

The zero volume adaptation is a continual learning process. This learning process is required to enable precise pre-injection for each individual fuel injector. Accurate metering of the very low pre-injection volume is necessary for the fulfilment of exhaust emission regulations.

Zero volume adaptation must be carried out on a continual basis due to the volume drift of the fuel injectors.

At each cylinder, a small amount of fuel is injected during overrun mode. This volume continues to increase until a slight increase in engine speed is detected by the digital diesel electronics.

The digital diesel electronic is thus able to detect when the respective cylinder begins to work. The volume of fuel injected during zero volume adaptation is used by the digital diesel electronics as a value for the characteristic map of pre-injection.

Zero volume adaptation takes place alternately from one cylinder to the next during the overrun phase at engine speeds from 1500 to 2500 rpm and with the engine at operating temperature.

Zero volume adaptation has no influence on fuel consumption as only very small quantity of fuel (about $1mm^3$) is injected at one cylinder at a time.

Mean Volume Adaptation

The mean volume (quantity) adaptation is a learning process in which the air/fuel ratio (lambda value) is corrected by the adjustment of the air mass or exhaust gas recirculation. Unlike the other processes, this process affects all fuel injectors equally rather than the individual fuel injector.

An injection volume averaged across all cylinders is calculated from the lambda value measured by the oxygen sensor and the air mass measured by the hot-film air mass meter. This value is compared with the injection volume specified by the digital diesel electronics.

If a discrepancy is detected, the air mass is adjusted to match the actual injection volume by an adjustment of the exhaust gas recirculating valve. The correct lambda value is set in turn.

The mean volume adaptation is not an "instantaneous" regulation but an adaptive learning process. The injection volume error is taught into an adaptive characteristic map that is permanently stored in the EEPROM of the control unit.

Replacing the following components will require a reset (clearance) of this mean volume adaptation characteristic map:

- Hot-film air mass meter
- Fuel injector(s)
- Rail pressure sensor

It is possible to reset the characteristic map with the BMW diagnosis system.

NOTES PAGE

Workshop Exercise - Fuel Supply System

1. *Fill in the chart below while performing the test module for the EKP:*

Item	Value
Voltage, fuel pump	
Current, fuel pump	
Specified delivery rate	

2. *Carry out the service function for bleeding the fuel system.*

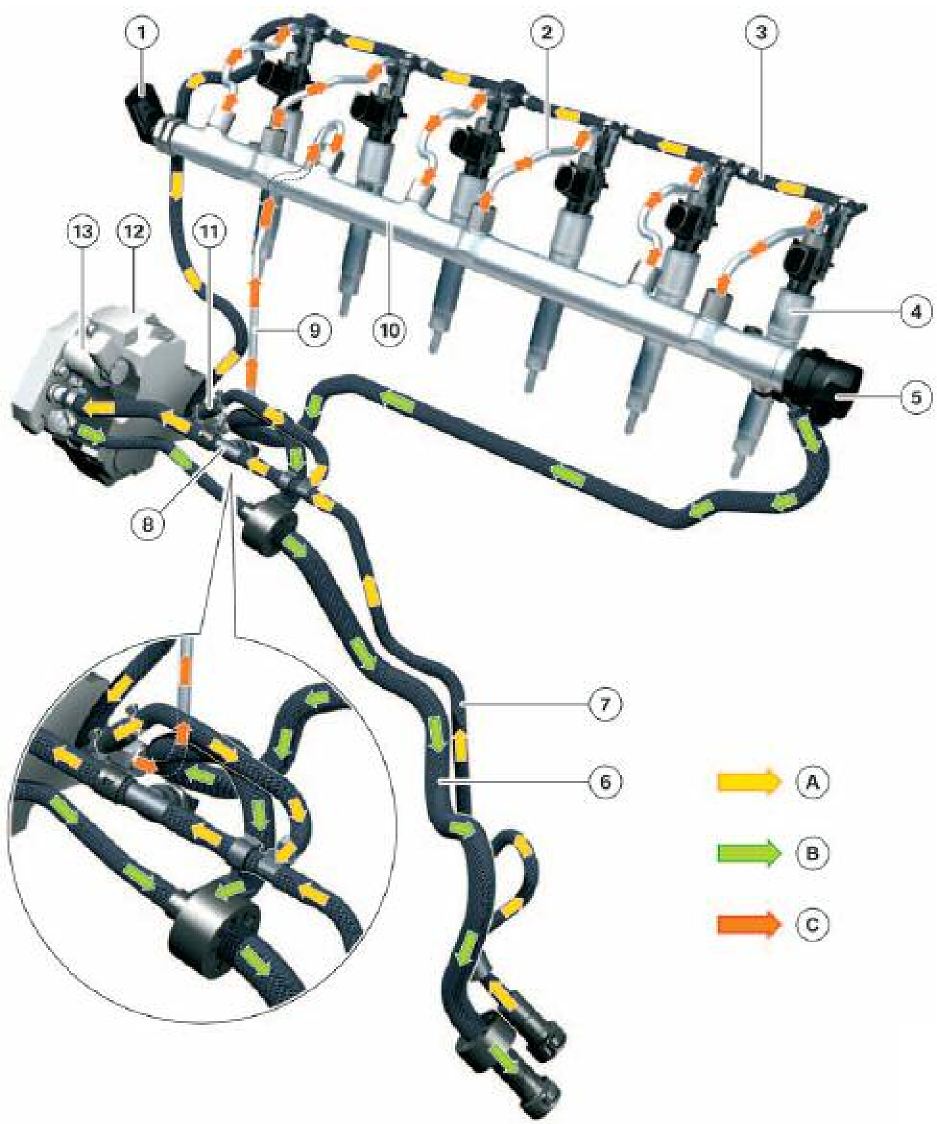
   When would this procedure be required?

3. *Carry out the plausibility test for the fuel pressure/temperature sensor:*

Item	Value
Fuel temperature	
Fuel pressure (E70 only)	

Workshop Exercise - High Pressure Fuel System Component Location / Identification

1. Complete the chart by filling in the functions for the listed components, then locate on the vehicle:



Index	Explanation	Function/Purpose
A	Fuel feed (low pressure)	
B	Fuel return	
C	Fuel high pressure	
1	Fuel rail pressure sensor	
2	High pressure line	
3	Leakage line	
4	Piezo injector	
5	Fuel rail pressure control valve	
6	Return line	
7	Feed line	
8	Fuel temperature (or temp/pressure)	
9	High pressure line	
10	Fuel rail	
11	Restrictor	
12	High pressure pump	
13	Volume control valve	

Workshop Exercise - High Pressure Fuel System

1. *Using the "read measured values" test modules in service functions, please complete the following table:*

	Cold	Hot
Engine speed		
Coolant temperature		
Rail pressure, actual		
Rail pressure, target		
Injection volume, mg		

2. *With the engine at operating temperature, please complete the following table regarding the rail pressure.*

Engine speed	Rail pressure (actual)	Activation pressure, control valve	Activation, volume control valve
Idle			
1000 rpm			
2000 rpm			
3000 rpm			

Workshop Exercise - High Pressure Fuel System

3. *Disconnect the rail pressure sensor and note the substitute value.* *Substitute value -* ______________________

   Is there any change to engine operation?

4. *Complete the test module for the rail pressure regulation valve. Record the resistance values in the chart below:*

Nominal value	Actual value

5. *Disconnect the volume control valve. Does the engine run? Explain why or why not?*

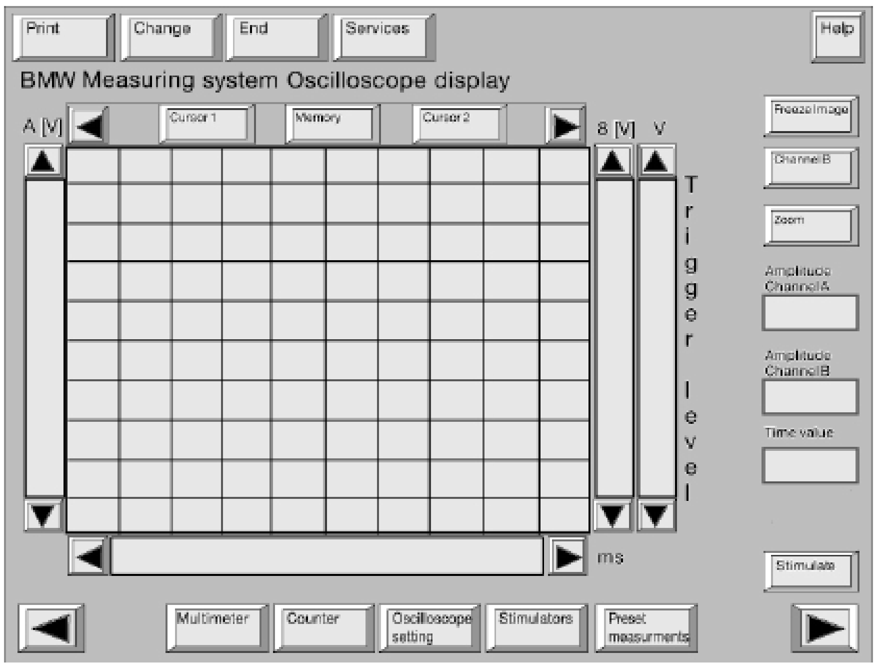
6. *Disconnect the pressure control valve? Does the engine run? Explain why or why not?*

Workshop Exercise - High Pressure Fuel System

7. *Perform the test module for the high pressure pump and complete the following chart:*

Amplitude (maximum)	Period duration

While performing above test module, obtain the oscilloscope pattern for the high pressure pump. Draw the pattern on the scope illustration provided.

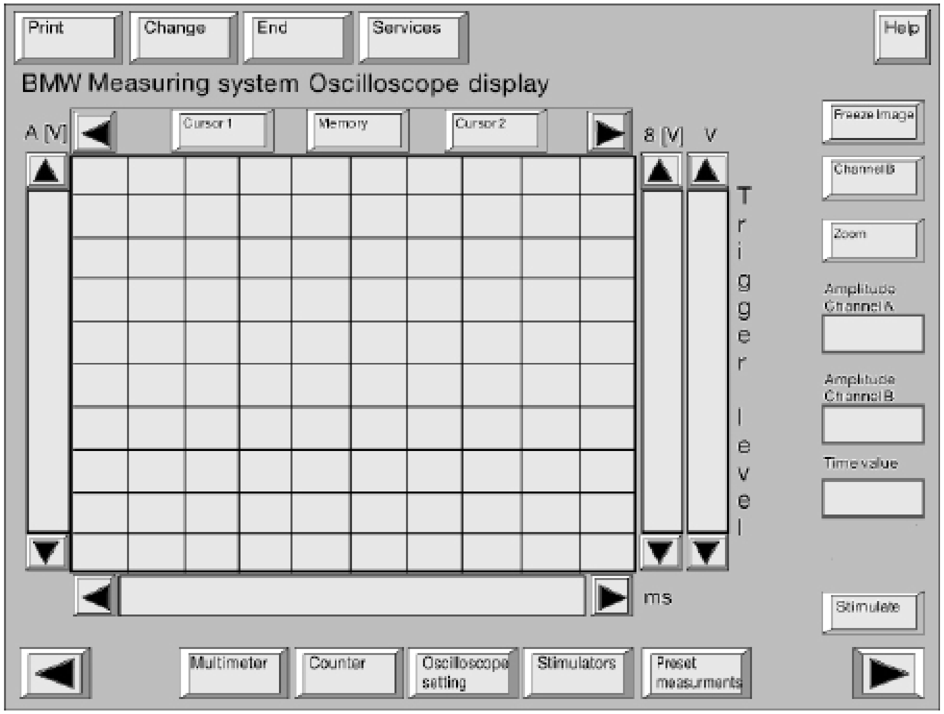


Item	Value
Test connections (MFK)	
Frequency settings	
Voltage level	
Trigger level	

Workshop Exercise - High Pressure Fuel System

8. *Obtain an oscilloscope pattern of the piezo injector and sketch your result below:*

WARNING!!! *High voltage may be present.*



Record Settings in the chart below:

Item	Value
Test connections (MFK)	
Frequency settings	
Voltage level	
Trigger level	

9. *Measure the resistance values of all injectors and record below:*

Injector 1	Injector 2	Injector 3	Injector 4	Injector 5	Injector 6

Workshop Exercise - High Pressure Fuel System

10. *Perform the test module/service function for the fuel injectors and complete the following table with the correct classification numbers and compare to those on the vehicle:*

Cylinder number	Classification
1	
2	
3	
4	
5	
6	

What type of fuel injectors are used in the M57D30T2 engine?

NOTES PAGE

Classroom Exercise - Review Questions

1. Which of the components listed below direct fuel to the return circuit for the operation of the siphon jet in the fuel tank? (circle those that apply)

Leakage line	Volume control valve
Rail pressure control valve	Restrictor
Fuel injectors	Fuel filter

2. In order to refuel a BMW diesel vehicle, there is a flap in the fuel tank to prevent misfueling. What is the correct diameter of the diesel fuel nozzle which is necessary to operate the misfueling flap? (circle one)

19 mm   21 mm   24 mm   34 mm

3. Which of the following components is ***NOT*** used on a diesel fuel system? (circle those that apply)

Electric fuel pump	Charcoal canister	Fuel filter
EKP module	Siphon jet	DM-TL

4. In order for the piezo injector to operate correctly, the pressure in the leakage circuit must be: (circle one)

100 bar or greater	Approximately 10 bar
3 to 5 bar	100 millibar
200 bar	1 bar +/- 100 millibar

5. In order to maintain the adequate pressure in the leakage line, a ______________________ is installed after the fuel injectors. (circle one)

check valve	non-return valve	restrictor
solenoid	bypass valve	coupler

6. For the US version of the diesel, which of the following fuel system components has been adapted to meet the US specific fuel specifications? (circle all that apply)

High pressure pump	Fuel filter
Volume control valve	Leakage line
Electric fuel pump	Fuel injectors
Fuel rail	Fuel filter heater

Classroom Exercise - Review Questions

7. Complete the following chart by checking the box for either E70 or E90 where it applies:

Component/System	E70 Xdrive35d	E90 335d
Screw-spindle fuel pump		
Gear-type (rotor) fuel pump		
Speed controlled low pressure fuel system		
Pressure controlled low pressure fuel system		
Fuel temperature/pressure sensor		
Fuel temperature sensor		
Low pressure EGR system		
High-pressure EGR system		
SCR system		
Diesel particulate filter		
Low pressure EGR cooler		
High pressure EGR cooler		

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.

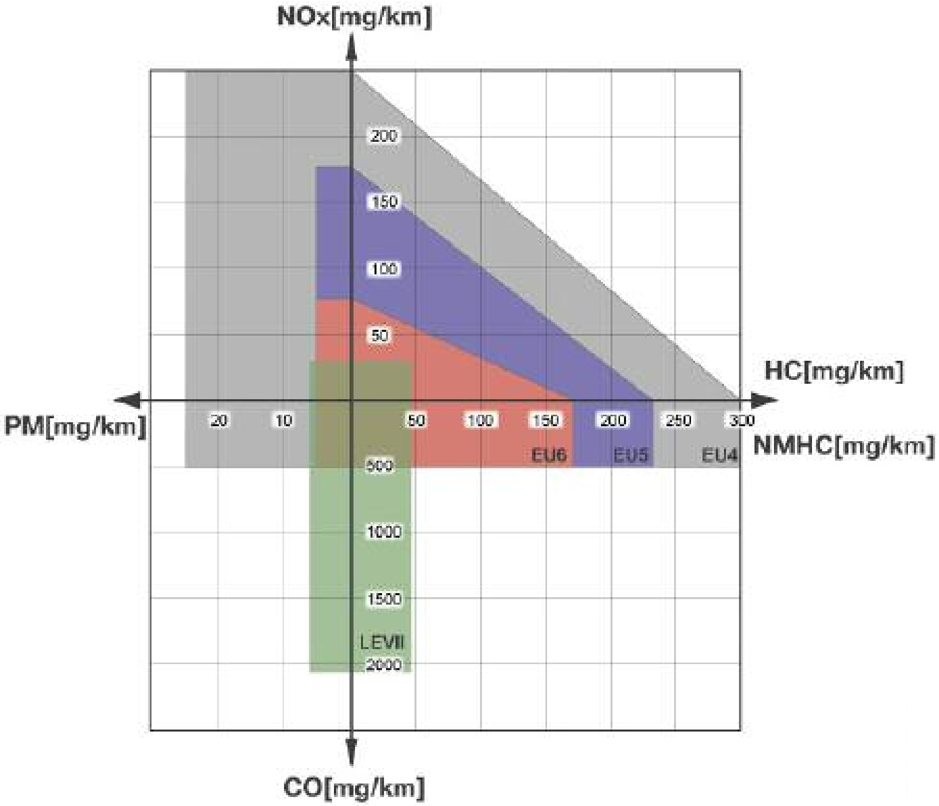
This legislation has lead to the development of different requirements with regard to the limitation of various components in the exhaust gas. Essentially, the following exhaust gas constituents are evaluated:

- 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 it’s 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:

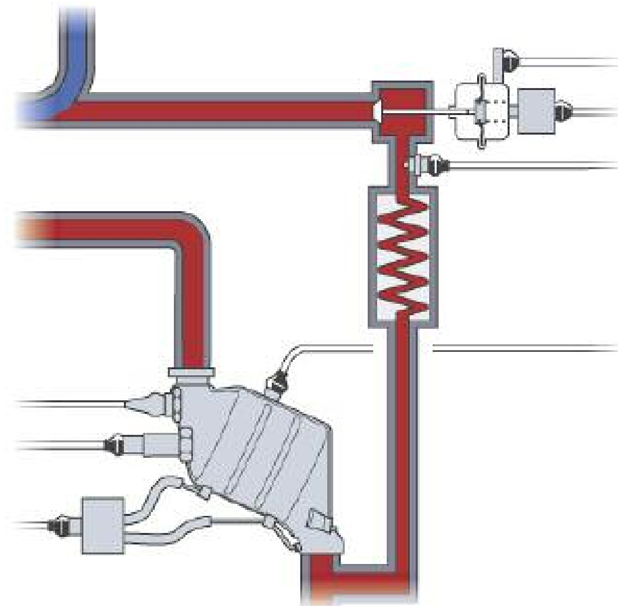
- Lower exhaust gas temperature - The exhaust gas for the low pressure EGR is tapped off at a point where a lower temperature prevails than in the high pressure EGR. Consequently, the exhaust gas has a higher density thus enabling a higher mass.

  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.

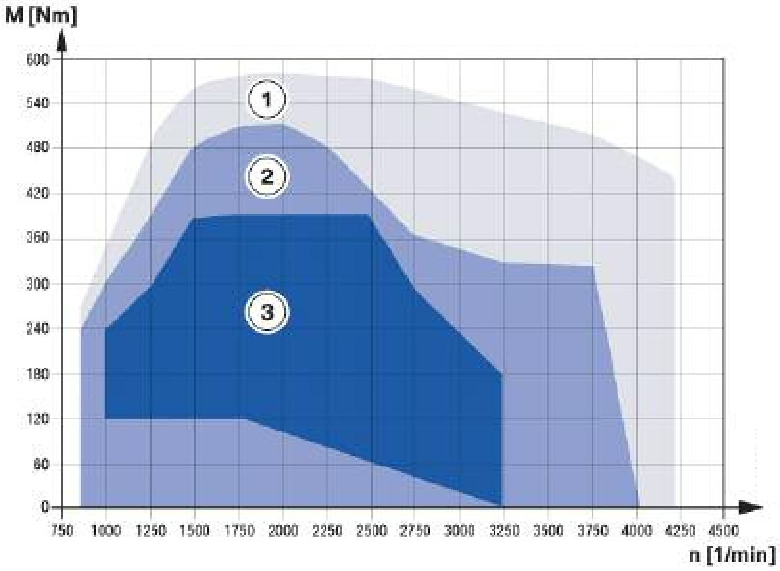
- Recirculation before the exhaust turbocharger - Unlike in the high pressure EGR where the exhaust gas is fed to the charge air already compressed, in this system the exhaust gas is added to the intake air before the exhaust turbocharger.
  A lower pressure prevails in this area under all operating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



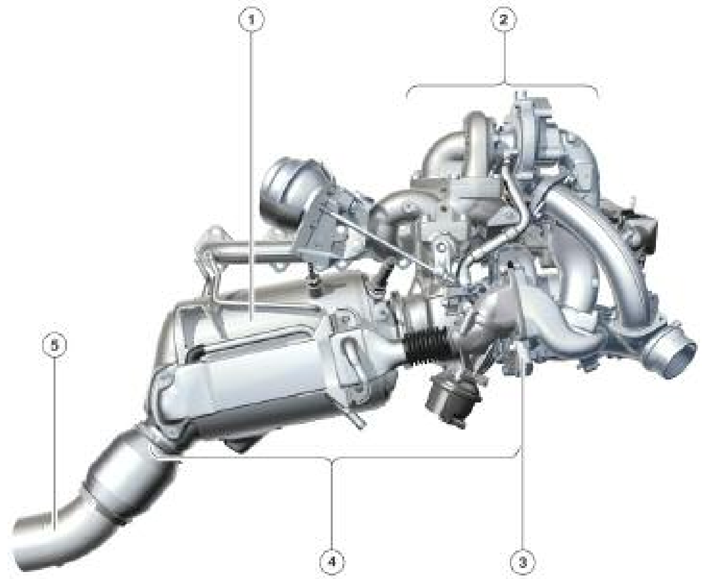
Index	Explanation	Index	Explanation
1	No EGR	3	High and low pressure EGR are active
2	Only high pressure EGR is active		

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.

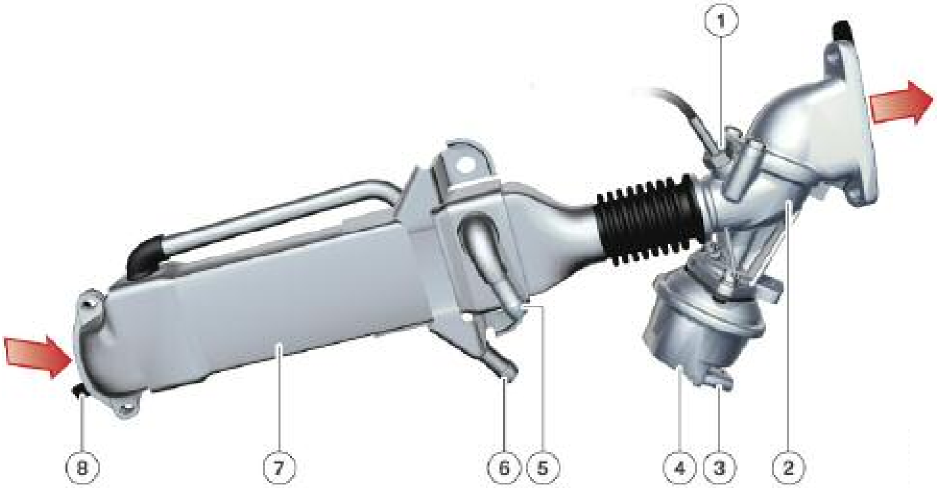
Added to this, it is only activated at a coolant temperature of more than 55°C. The low pressure EGR valve is closed as from a certain load level so that only the high pressure EGR valve is active again. This means the EGR rate is continuously reduced.

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:

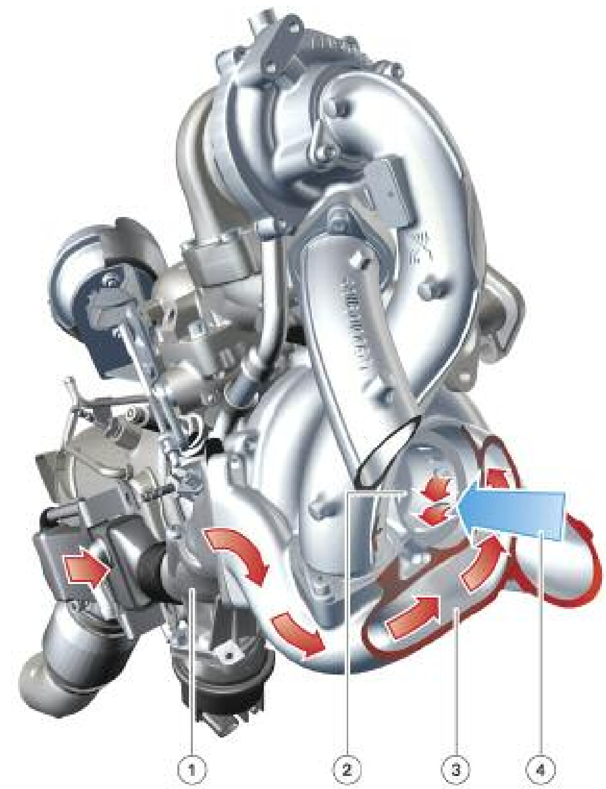


Index	Explanation	Index	Explanation
1	Temperature sensor - LP EGR	5	Coolant infeed
2	LP-EGR valve	6	Coolant return
3	Connection for positional feedback	7	LP-EGR cooler
4	Vacuum unit for LP-EGR valve	8	Sheet metal gasket with filter

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

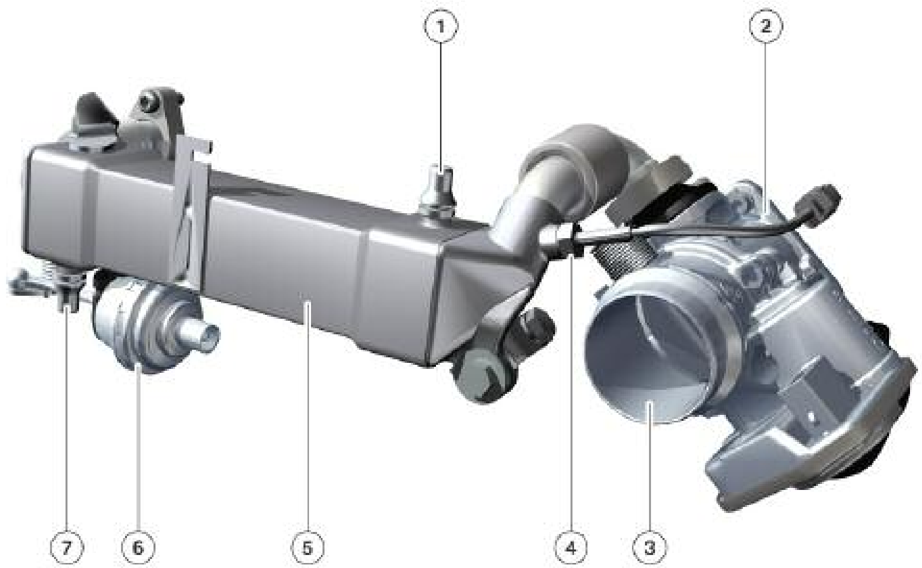
The US engine is equipped with the same variable twin turbo as the European version, however, the turbo assembly is modified due to the low pressure EGR.

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:

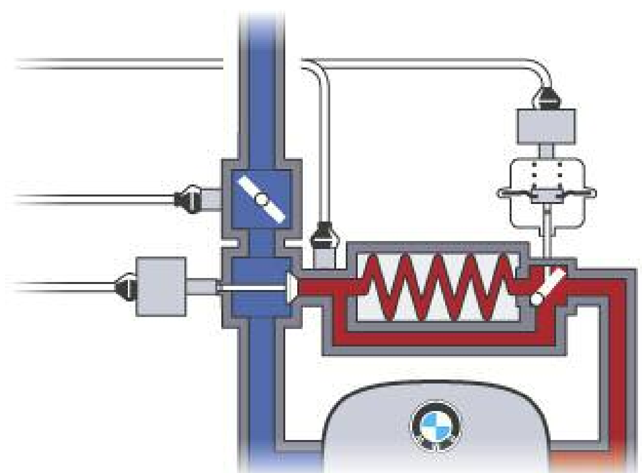
- Travel of high pressure EGR valve
- Temperature before high pressure EGR valve
- Pressure difference between exhaust gas pressure in the exhaust manifold and boost pressure in the intake manifold.

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.

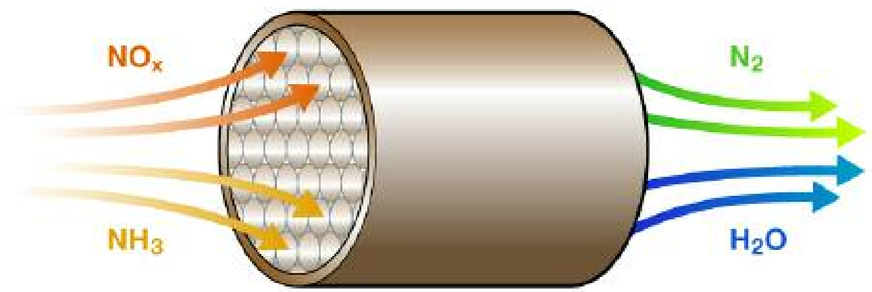
In this case, the EGR cooler can be bypassed in order to heat up the combustion chamber faster. For this purpose, there is a bypass that diverts the flow of the exhaust around the EGR cooler.

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, $(NH_2)_2CO$, 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.

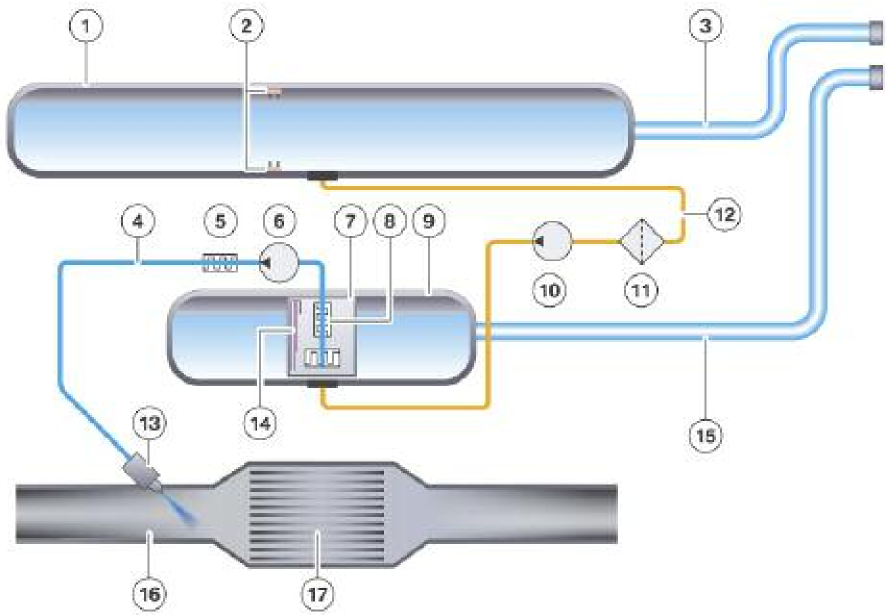
The AdBlue trademark is currently held by the German Association of the Automobile Industry (VDA), who ensure quality standards are maintained in accordance with DIN 70070 specifications.

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:



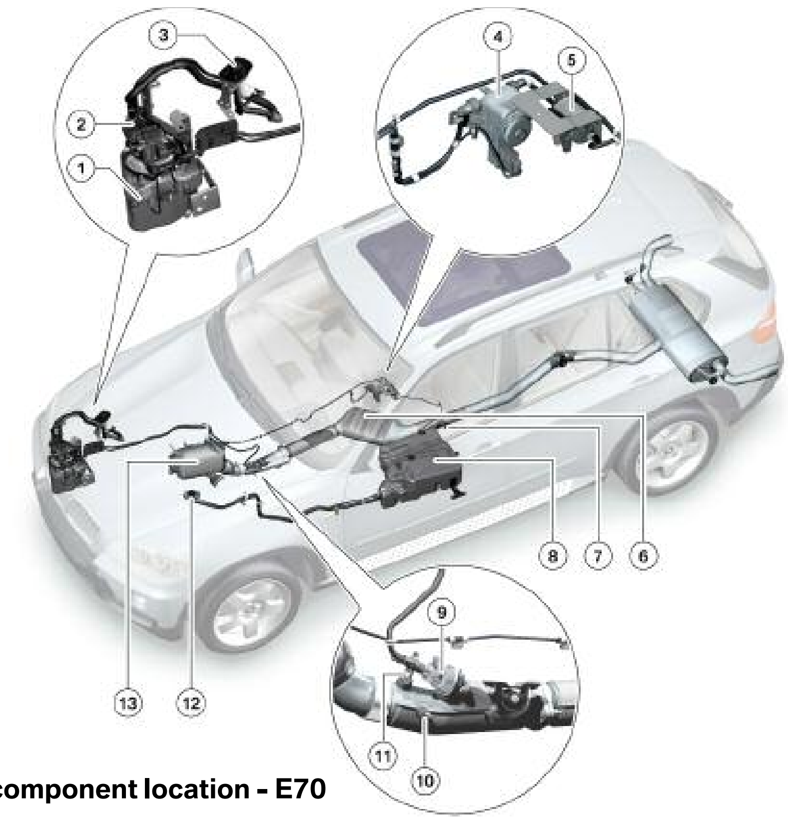
Index	Explanation	Index	Explanation
1	Passive reservoir	10	Transfer pump
2	Level sensors	11	Filter
3	Filler pipe, passive tank	12	Transfer line
4	Metering line	13	Metering module
5	Metering line heater	14	Level sensor
6	Pump	15	Filler pipe, active reservoir
7	Function unit	16	Exhaust system
8	Heater,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

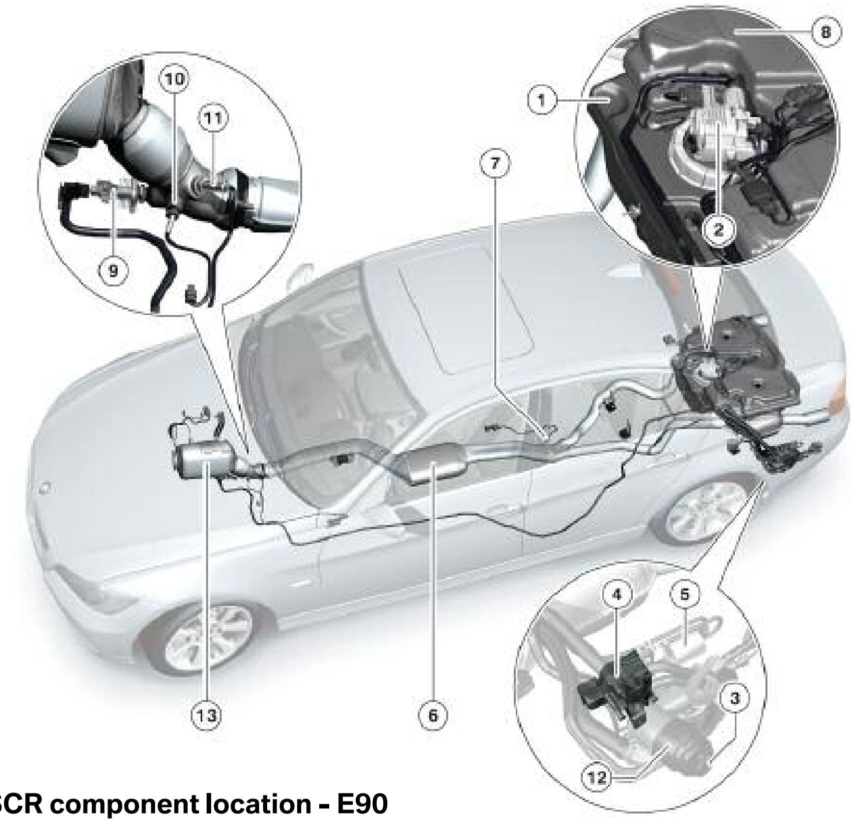


SCR component location - E70

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

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 - 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.

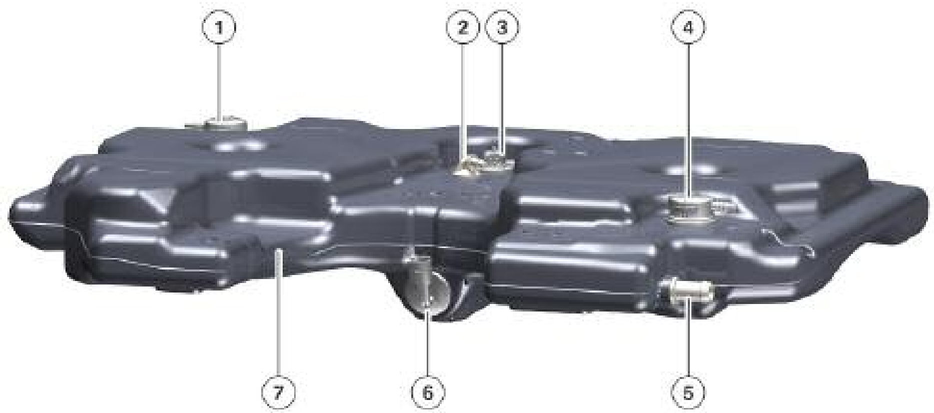
The fillers are located on the left-hand side behind the rear wheel where they are accessible through an opening in the bumper panel. The fillers are arranged in the same way as the reservoirs, i.e. the lower most is the filler for the active reservoir. The transfer unit and the filter are located behind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

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.

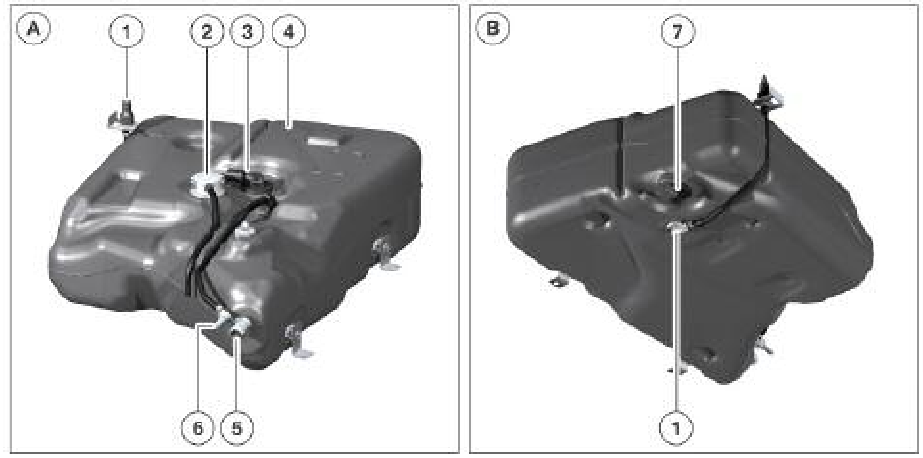
The following components make up the passive reservoir:

- 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.

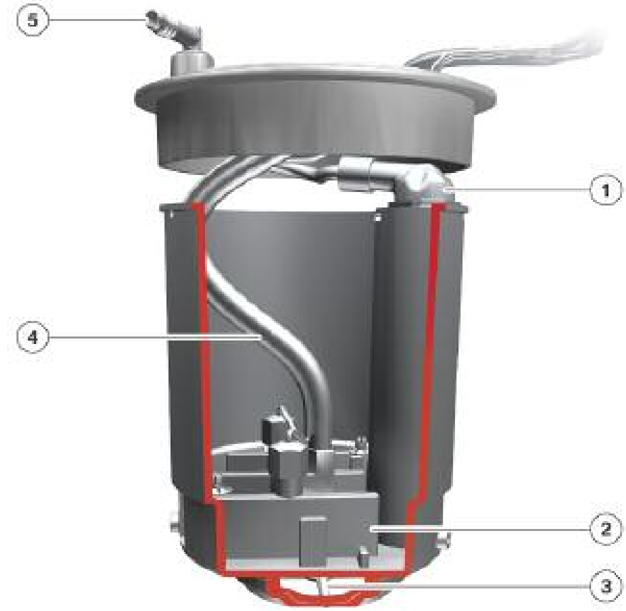
Unlike a surge chamber in the fuel tank, the lower section of the function unit has slots. This chamber creates a smaller volume in the reservoir that scarcely mixes with the urea-water solution outside the chamber.

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.

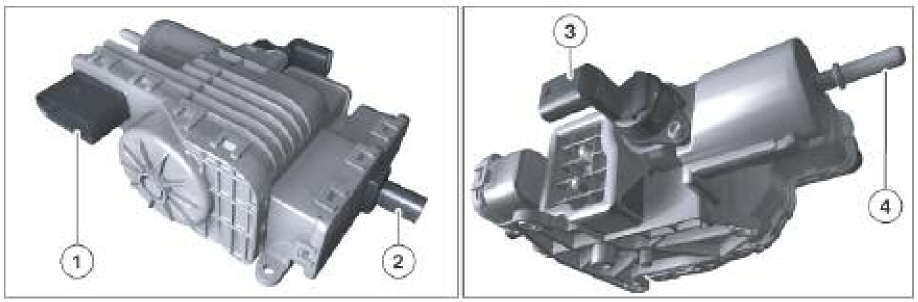
Three contacts are responsible for signalling the different levels. The fourth contact is the reference, i.e. the contact via which the electric circuit is closed. This reference contact cannot be seen in the figure as it is located directly behind the "Empty" contact (3).

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

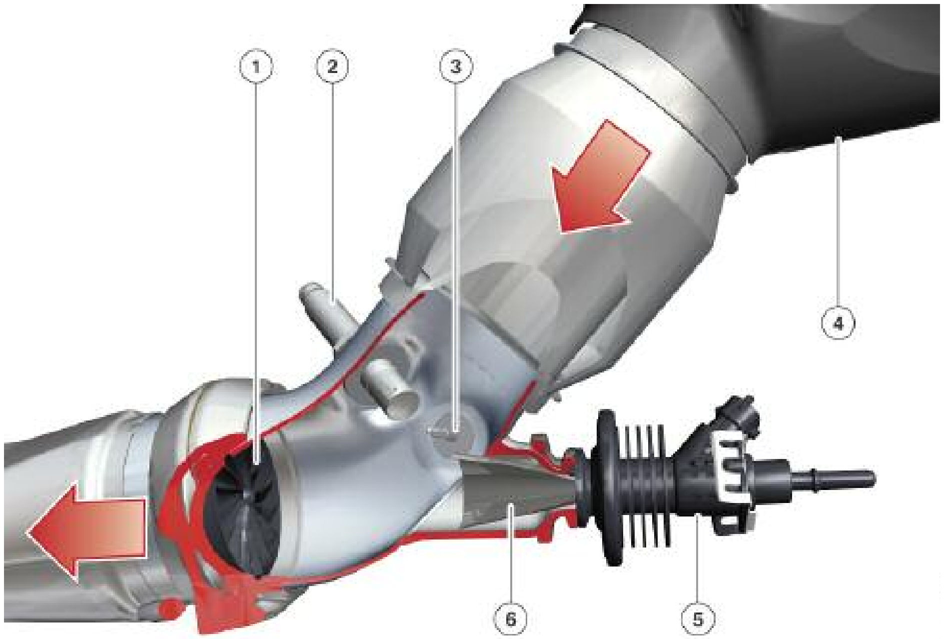
The metering module is responsible for injecting the urea-water solution into the exhaust pipe. It features a valve that is similar to the fuel injector in a petrol engine with intake manifold injection.

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.

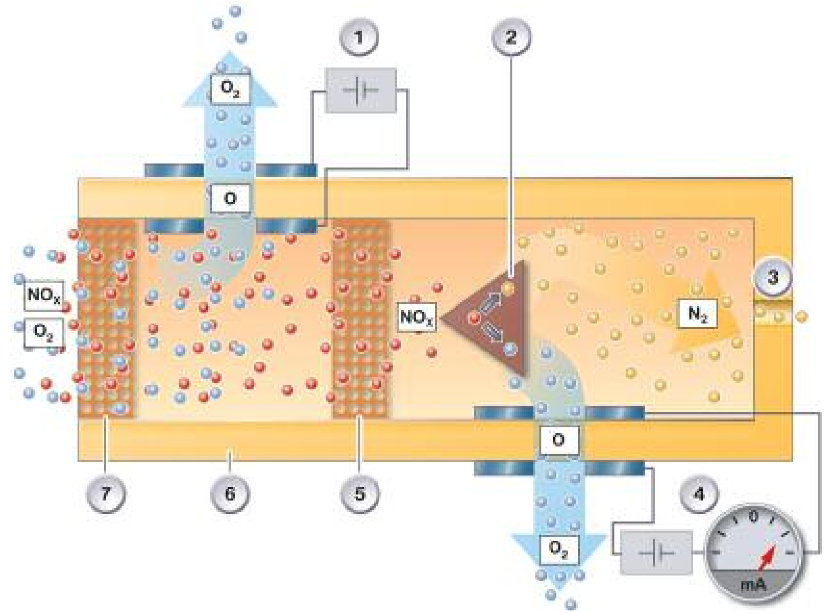
The exhaust gas flows through the NO_X sensor. Here, only oxygen and nitrogen oxides are of interest. In the first chamber, the oxygen is ionized out of this mixture with the aid of the first pump cell and passed through the solid electrolyte.

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.

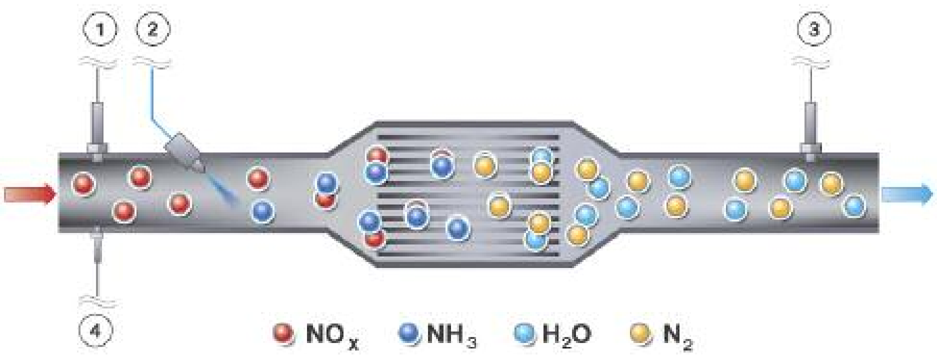
The following graphic shows the functional principle of this measuring system.



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.



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.

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

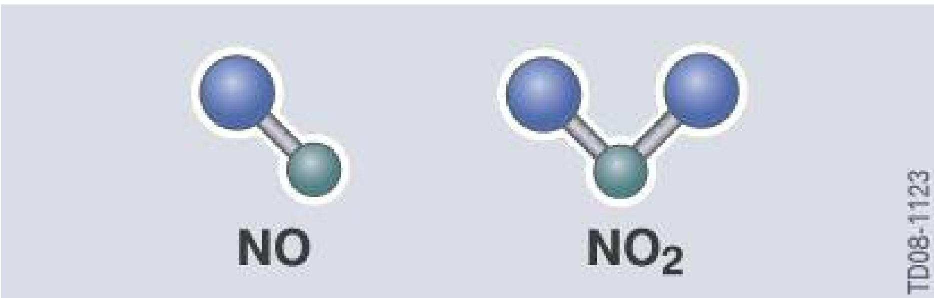
A further NO_X sensor that monitors this function is located downstream of the SCR catalytic converter.

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).

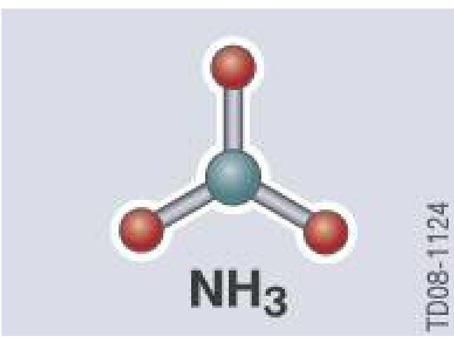
Chemical Reaction

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:

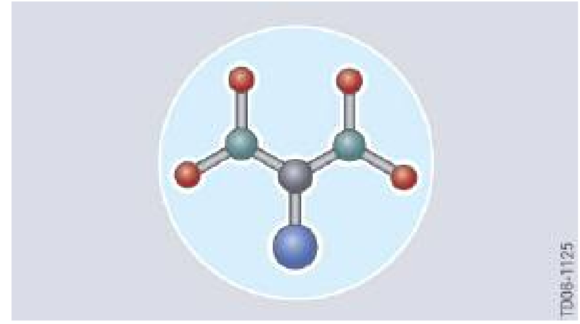
- Nitrogen monoxide (NO)
- Nitrogen dioxide (NO_2).



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

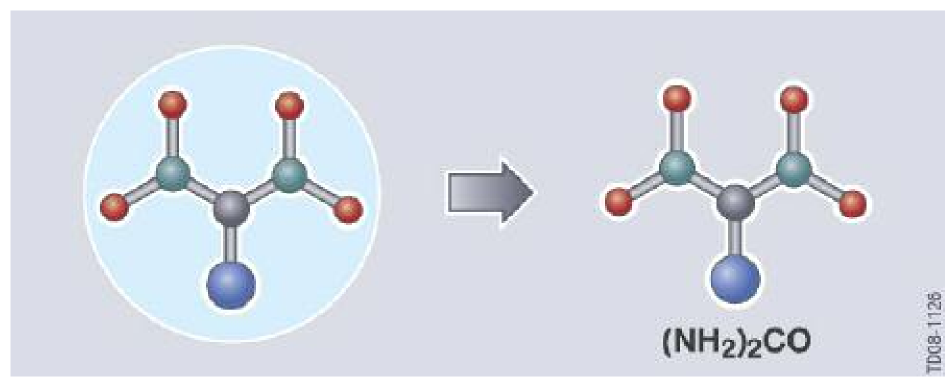


The urea-water solution is injected by the metering system into the exhaust system downstream of the diesel particulate filter. The required quantity must be metered exactly as otherwise nitrogen oxides or ammonia would emerge at the end. The following description of the chemical processes explains why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

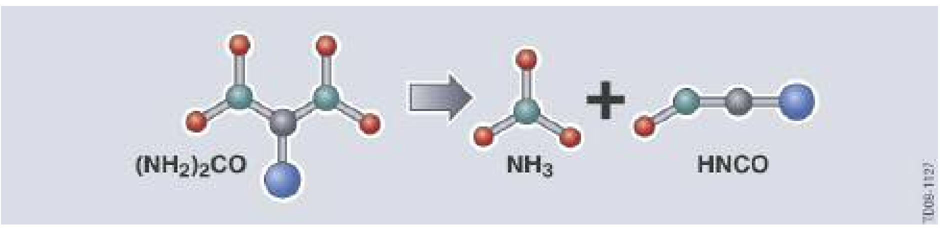
Initially, the urea ($(NH_2)_2CO$) dissolved in the urea-water solution is released. The conversion of urea into ammonia takes place in two stages.



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 $(NH_2)_2CO$
Result:	Ammonia (NH_3) Isocyanic acid (HNCO)
Chemical Formulas:	$(NH_2)_2CO > NH_3 = HNCO$

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.

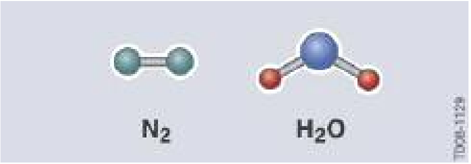
Hydrolysis	
Explanation:	The isocyanic acid that was produced during thermolysis is converted into ammonia and carbon dioxide (CO_2), by the addition of water in the hydrolysis process.
Initial Products:	Isocyanic acid (HNCO) Water (H_2O)
Result:	Ammonia (NH_3) Carbon dioxide (CO_2)
Chemical Formulas: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

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

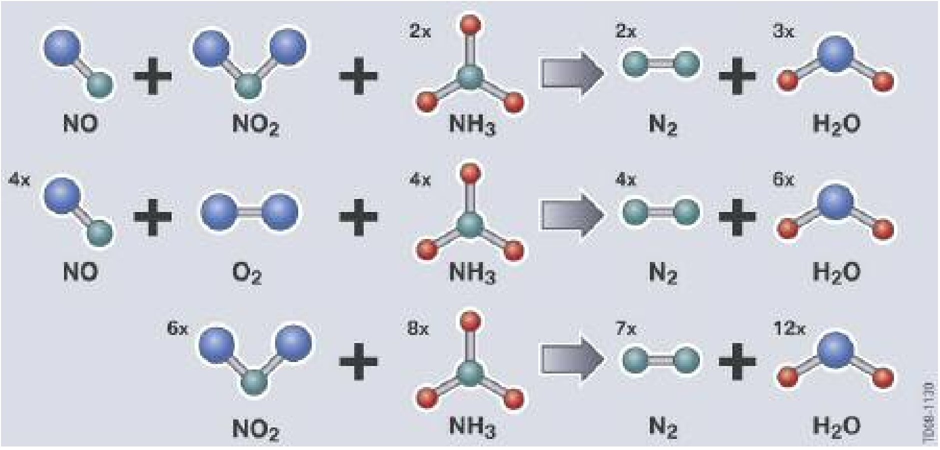
The water required for this purpose is also provided by the urea-water solution. Therefore, following hydrolysis, all the urea is converted into ammonia and carbon dioxide.

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_2O)
Chemical Formulas:	$NO + NO_2 + 2NH_3 > 2N_2 + 3H_2O$ $4NO + O_2 + 4NH_3 > 4N_2 + 6H_2O$ $6NO_2 + 8NH_3 > 7N_2 + 12H_2O$



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

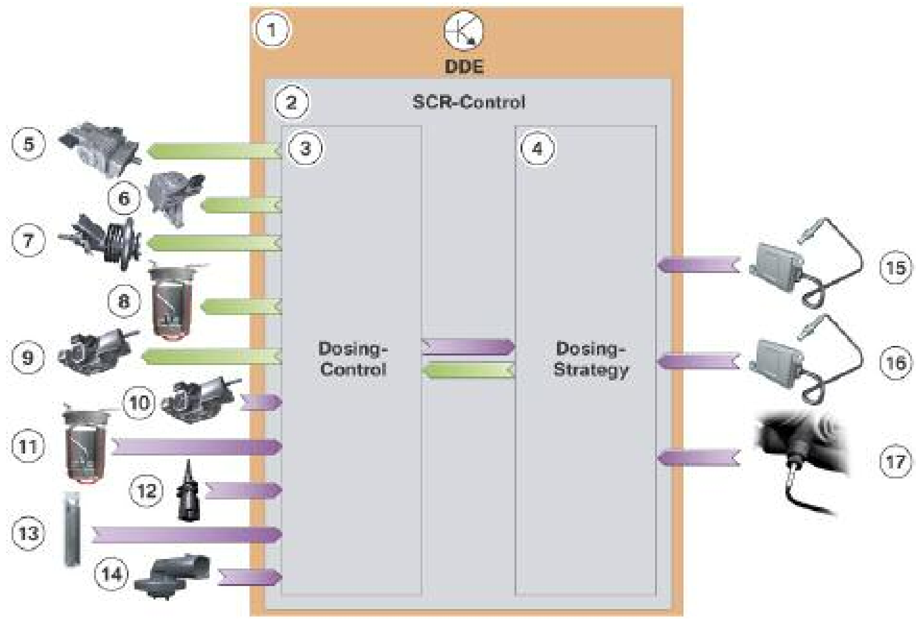
It can be seen that each individual atom has found its place again at the end of the process, i.e. exactly the same elements are on the left as on the right.

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.

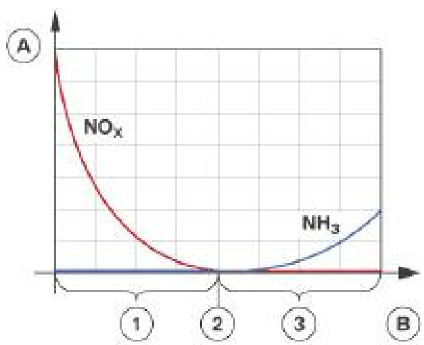
SCR Control

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

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.

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.

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°C	< -4°C	< -5°C	< -9°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.

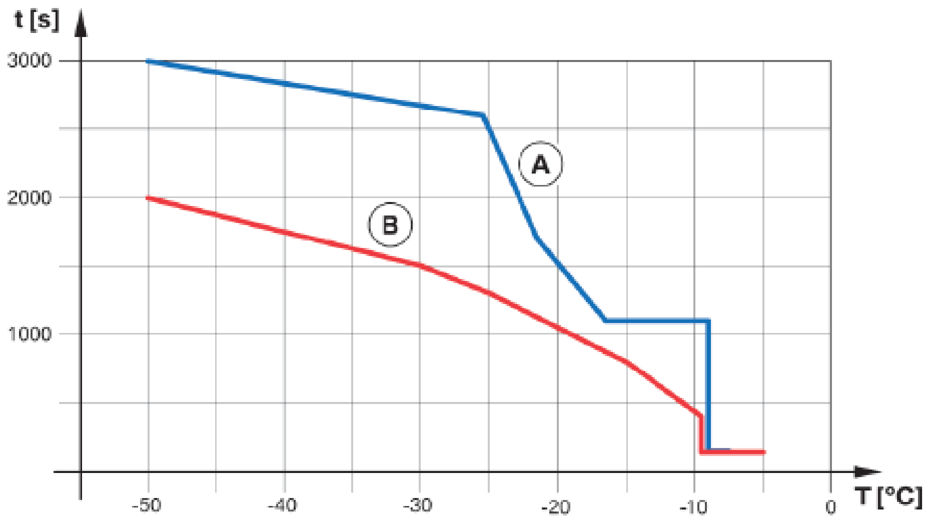
This time is constant from -9°C to -16.5°C as it is not possible to determine to what extent the urea-water solution is frozen.

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.

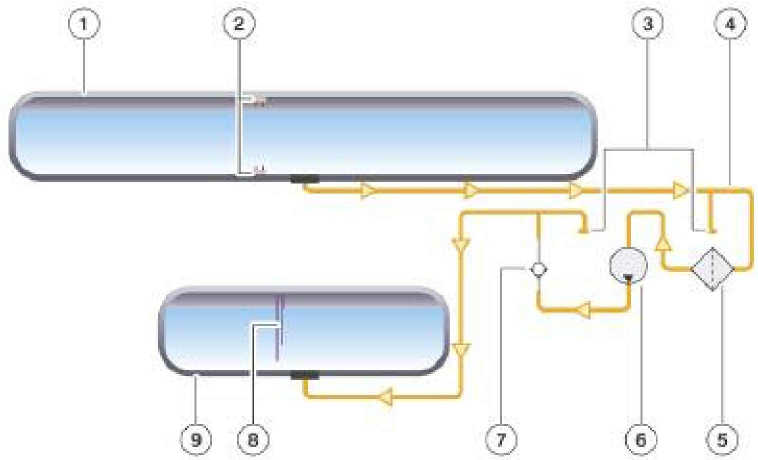
The delay time that is initiated by the temperature in the active reservoir is approximately 18 minutes while the delay time initiated by the ambient temperature is 25 minutes. Since the delay time initiated by the ambient temperature is longer, this will give rise to a longer delay.

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.

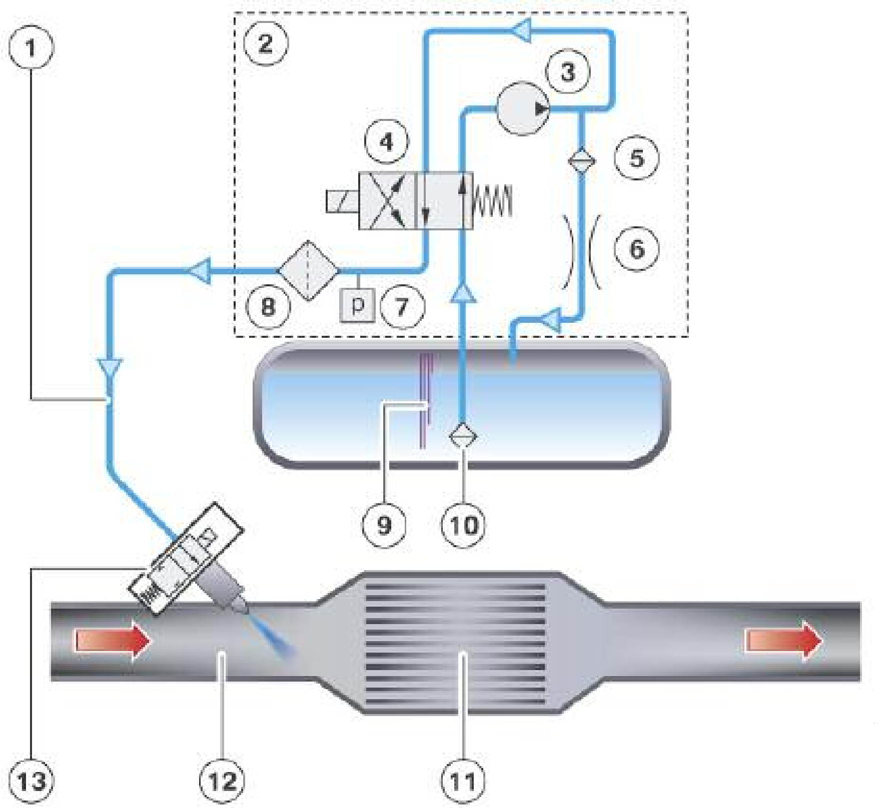
This function determines whether the system has been filled with the wrong medium as it is present in high concentration in the active reservoir.

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		

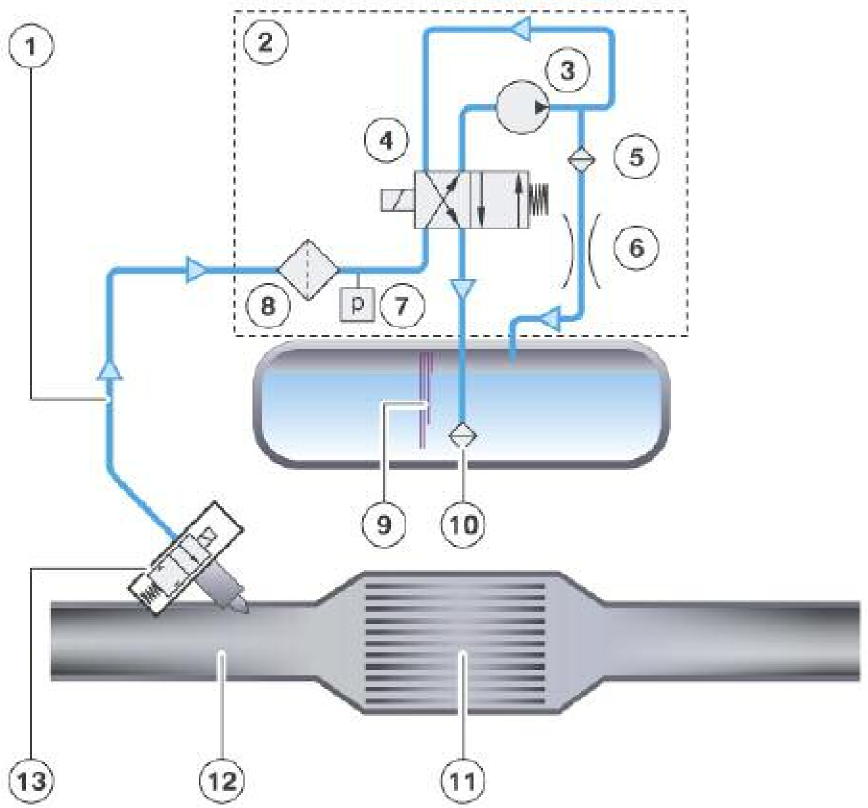
The pump is actuated by a pulse-width modulated signal (PWM signal) from the DDE. The PWM signal provides a speed specification for the purpose of establishing the system pressure. The value for the speed specification is calculated by the DDE based on the signal from the pressure sensor.

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

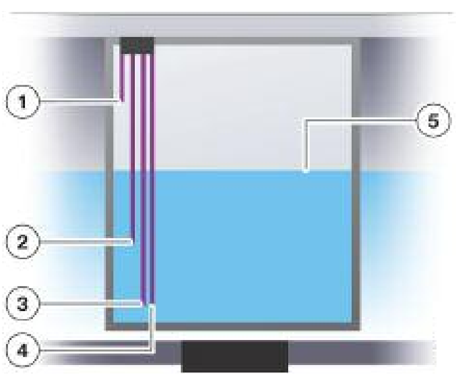
There are level sensors both in the active as well as in the passive reservoir. However, these sensors are not continuous sensors as in the fuel system for example. They can determine only a specific point, to which a defined quantity of urea-water solution in the reservoir is assigned.

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.

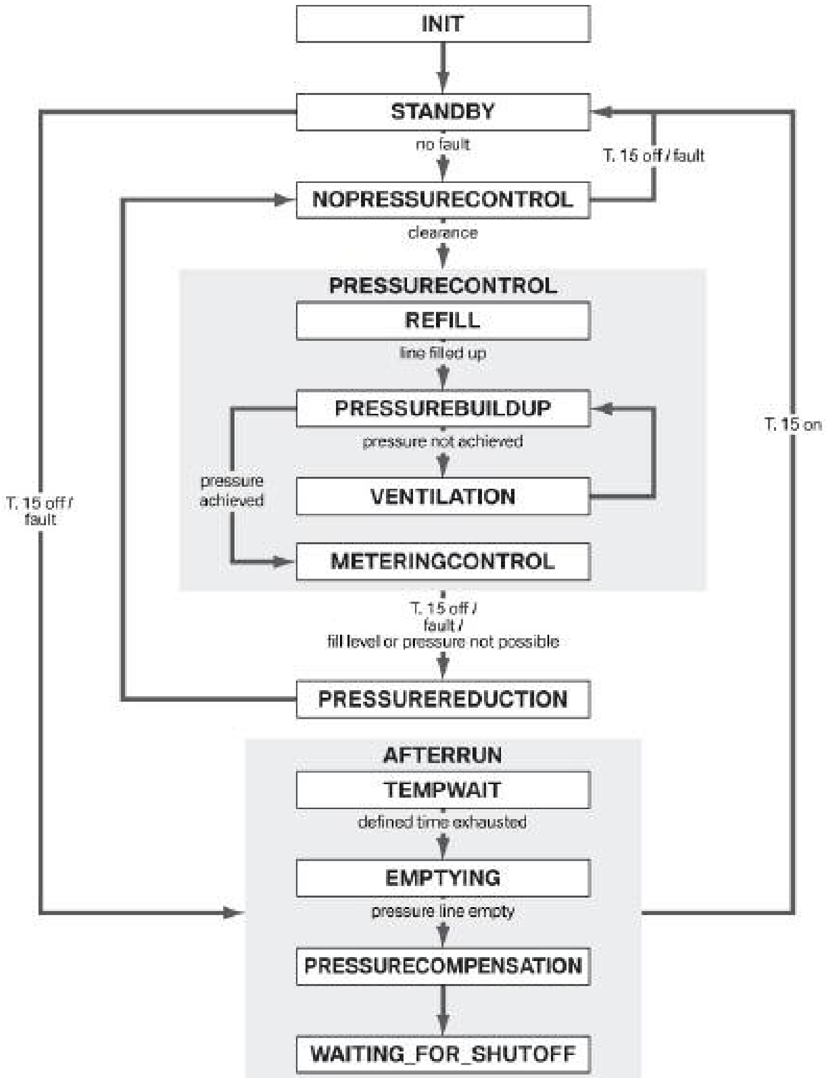
Normally, the level then drops below the next lower level sensor at the same time as determined by the level calculation. An adjustment takes place at this point and the calculation is restarted.

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

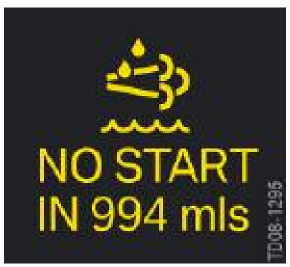
The warning scenario begins when the level drops below the "Warning" level sensor in the active reservoir. At this point, the active reservoir is still approximately 50% full with urea-water solution. The level is then determined as a defined volume (depending on type of vehicle).

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.

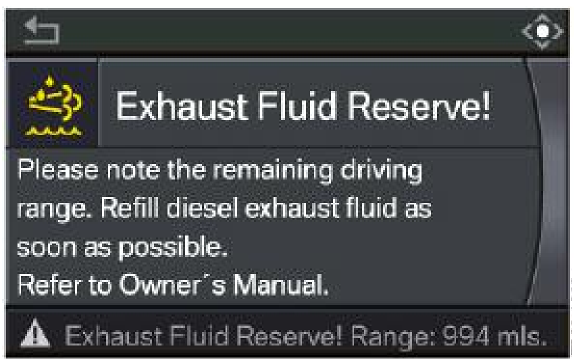
A countdown from 1000 mls now takes place irrespective of the actual consumption of the urea-water solution. The driver receives a priority 2 (yellow) check control message showing the remaining range.

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.

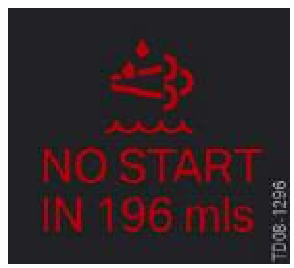
The following messages and indicators will be displayed:



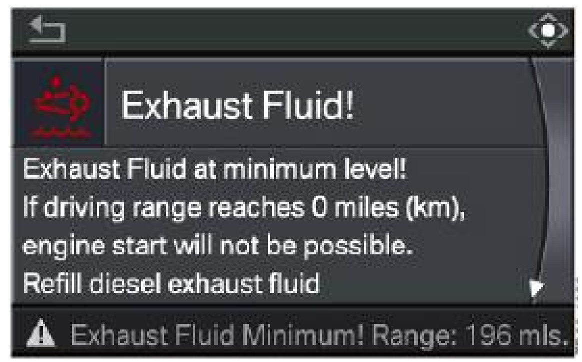
CC message in cluster, range < 1000 miles



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.

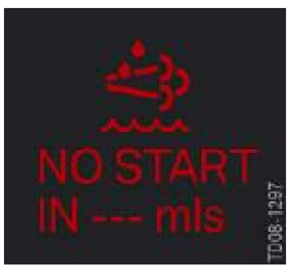
In this case, it will no longer be possible to start the engine if it has been shut down for longer than three minutes. This is intended to allow the driver to move out of a hazardous situation if necessary.

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.

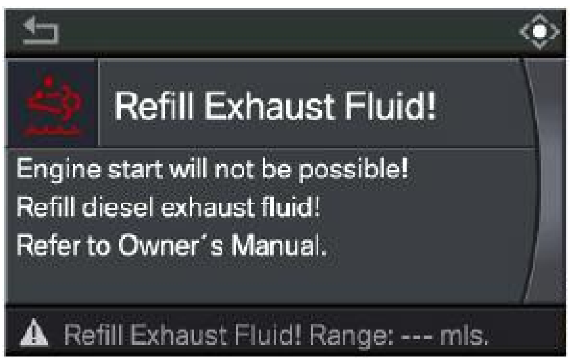
Exhaust Fluid Incorrect

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.

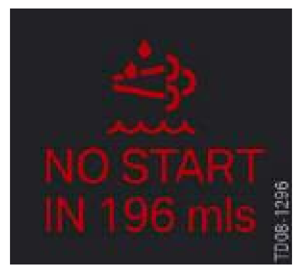
The exclamation mark in the symbol identifies the fault in the system. In this case, the message in the CID informs the driver to go to the nearest workshop.



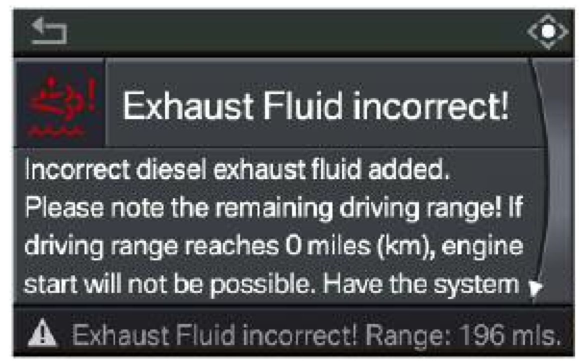
CC message in cluster, range = 0 miles



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**	**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**	**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**	597.20	**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

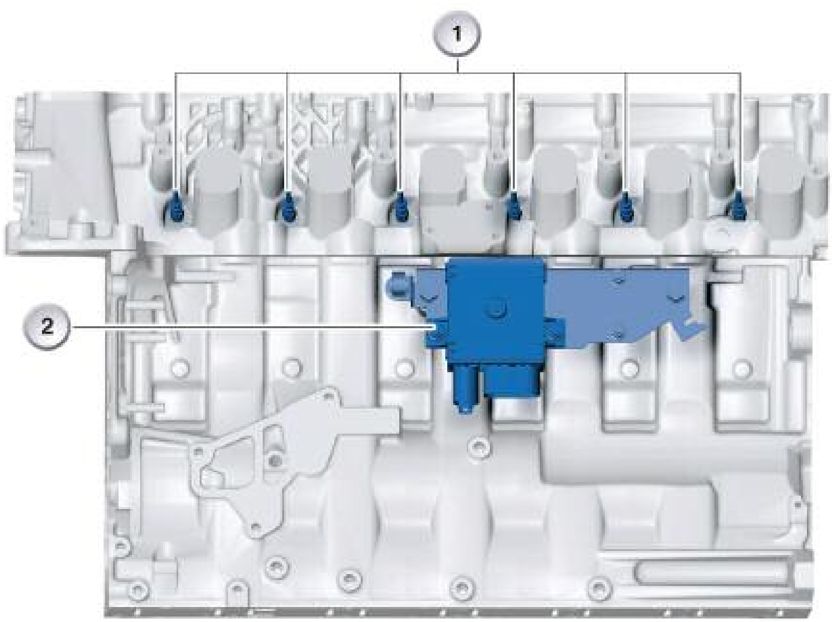
Diesel Auxiliary Systems

Glow-plug System

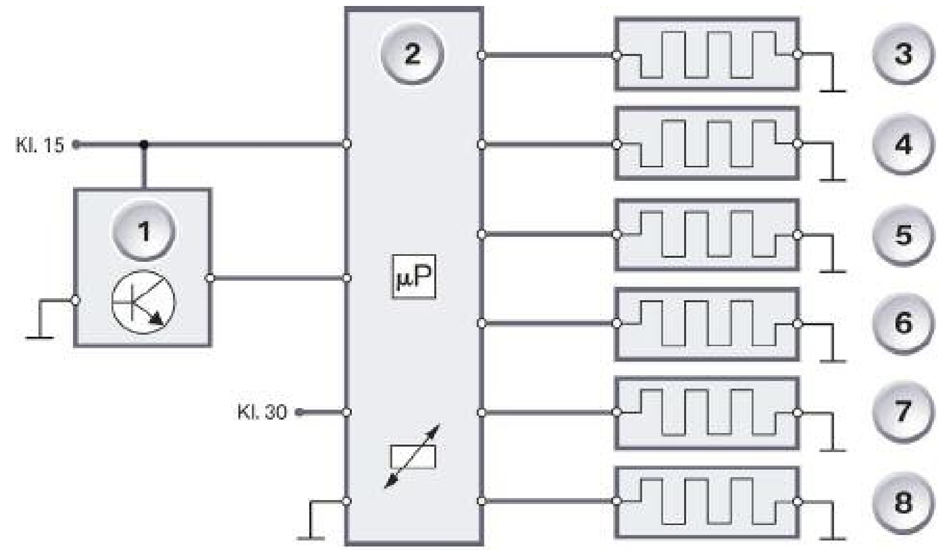
The glow-plug system is responsible for providing reliable cold start properties and smooth operation when the engine is cold.

The DDE control module sends the temperature requirement of the heater plug to the heating control unit. The heating control unit implements the request and actuates the heater plugs with a pulse-width modulated signal.

The heating control unit additionally sends diagnosis and status information via the LIN-bus connection back to the digital diesel electronics.



Index	Explanation	Index	Explanation
1	Glow plugs	2	Glow plug control module



Index	Explanation
1	DDE
2	GSG
3-8	Glow plugs (Cylinders 1-6)

The LIN-bus is a bi-directional data interface that operates in accordance with the master/slave principle. The DDE control unit is the master.

Each of the six heating circuits can be diagnosed individually.

When the heating control unit is switched on for the first time, the electrical resistance of the heater plugs is evaluated at the start of the heating process. A hot heater plug has a much higher resistance than a cold plug. If hot heater plugs are detected based on their resistance, less power is applied to the heater plugs at the start of the heating cycle.

If, on the other hand, cold heater plugs are detected, the maximum power is applied to the heater plugs at the start of the heating cycle. This function is known as dynamic repeat heating. This function avoids the situation where too much power is applied to a heater plug, which is already hot, as the result of a second heating cycle following shortly after the first, and therefore overheats.

The DDE control unit determines the necessary heater plug temperature as a function of the following operating values:

- Engine speed
- Intake air temperature
- Injected quantity
- Ambient pressure
- System voltage
- Status signal, starter enable.

The digital diesel electronics sends the required heater plug temperature to the heating control unit to activate heating.

The heating system assumes various operating modes that are explained in the following.

Preheating

Preheating is activated after terminal 15 has been switched on. The heater system indicator in the instrument cluster is activated at a coolant temperature of ≤ 10°C.

Preheating is finished when:

- The engine speed threshold of 42 rpm is exceeded (starter is operated) or
- the preheating time has elapsed. The preheating time is dependent on the coolant temperature and is defined in a characteristic curve.

Coolant temperature in °C	Preheating time in seconds
< - 35	3.5
- 25	2.8
- 20	2.8
- 5	2.1
0	1.6
5	1.1
30	1.1
> 30	0

Start Standby Heating

Start standby heating is activated when the preheating process is terminated by the preheating time elapsing. Start standby heating is terminated:

- After 10 seconds or
- when the engine speed threshold of 42 rpm is exceeded.

Start Heating

Start heating is activated during every engine start procedure when the coolant temperature is below 75°C. Start heating begins after the engine speed threshold of 42 rpm has been exceeded.

Start heating is terminated:

- After the maximum start heating time of 60 seconds has elapsed or
- after the engine start operation has been completed or
- when the coolant temperature of 75°C is exceeded.

Emergency Heating

Emergency heating is triggered for 3 minutes in the event of communication between the DDE control unit and heating control unit failing for more than 1 second.

The heating control unit then uses safe values so as to prevent damage to the heating system.

Concealed Heating

Preheating and start standby heating are activated as so-called concealed heating up to a coolant temperature of 30°C.

Concealed heating is triggered a maximum of 4 times and is then not enabled again before the engine is restarted.

Concealed heating is triggered by the following signals:

- Driver's seat occupancy
- Driver's seat belt buckle
- Valid key
- Terminal R
- Clutch operated.

Partial Load Heating

Partial load heating can occur at coolant temperatures below 75°C after starting the engine. Actuation of the heater plugs depends on the engine speed and load, thus improving the exhaust gas characteristics.

Actuation and Fault Detection

The power output stages for heater plug actuation are located in the heater control unit. The heater control unit does not have its own fault code memory. Faults in the heating system detected by the heater control unit are signalled via the LIN-bus to the digital diesel electronics.

The corresponding fault codes are then stored in the DDE fault code memory.

To avoid damage, the heater control unit shuts down all heating activities when the permissible operating temperature of the heater control unit is exceeded.

The ceramic heater plugs are designed for an operating voltage of 7.0 to 10.0 V. A voltage of 10 V can be applied to heat up the plug at a faster rate during the heating process. A PWM signal is applied to the heater plugs for the purpose of maintaining the heater plug temperature.

Consequently, an effective voltage is established at the heater plugs that is lower than the system voltage.

Note: The ceramic heater plugs are susceptible to impact and bending loads. Heater plugs that have been dropped may be damaged.

Note: A maximum voltage of 7 V may be applied to the heater plugs when removed. Higher voltages without cooling air movement can irreparably damage the heater plugs.

NOTES PAGE